TELESCOPE MAKING 13

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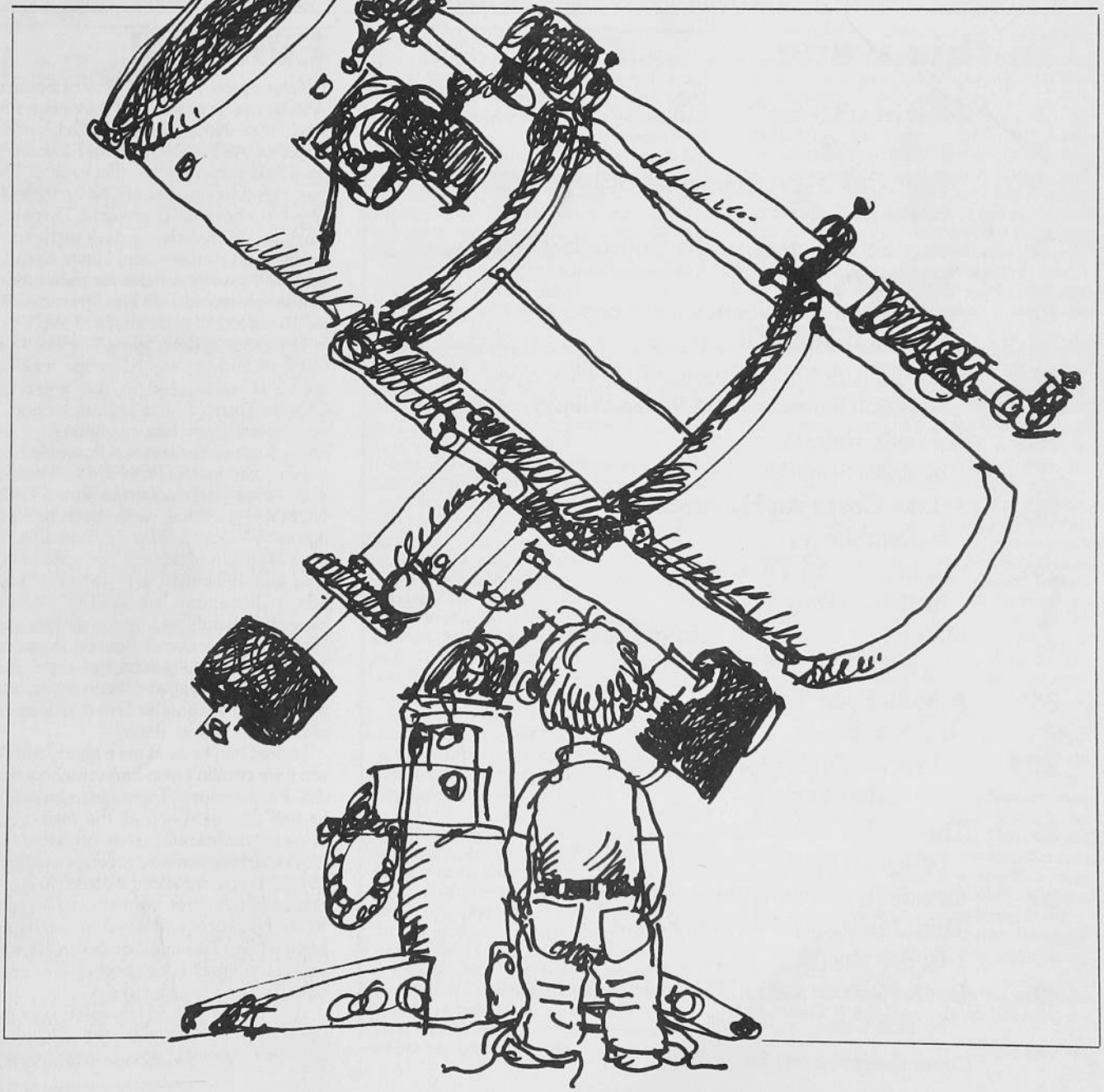
The magazine for and about telescope makers!

Fall 1981



TELESCOPE MAKING

The magazine *for*, *by* and *about* telescope makers!

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Editorial

Between covering the flyby of Saturn, writing the articles, and planning the super-size November and December issues of ASTRONOMY that followed, I'm a little surprised that this issue of TM ever came to completion. Nevertheless, here it is, chock full of projects. There is a stack of TM mail on my desk with more articles and pictures, and I have already prepared several articles for publication that simply wouldn't fit into this issue. So we'll have lots of good stuff in TM#14....

The most serious issue I've encountered recently in our telescope making hobby is epitomized in the letter by Charles Turner in our Letters section. I first heard from him by phone — he wanted me to denounce a firm he'd had trouble with in ASTRONOMY. "Well," I said, "they don't advertise in ASTRONOMY — besides, we've been burned before. We got sued for 8 million dollars. It's a legal can-of-worms." Despite being "big and influential" and carrying their ads, publications like ASTRONOMY have their hands tied by the danger and incredible expense of fighting lawsuits. You lose financially even if you win. But the problem is real, and it continues, and it hurts every reputable firm that deals by mail. What can be done?

I asked him to send me a letter, and I'd see if we couldn't help him somehow. He did. Furthermore, Turner sent his letter to half the clubs and all the mail-order firms in the United States, probably the most effective possible revenge available to him. I received about a dozen Xerox® copies of the letter from all over — sent to me by people who'd gotten his letter. Meanwhile, Turner's advice on how to protect yourself is as good as any I can offer.

Richard Berry

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Letters

Dear Richard / "Newtonian Aberrations" in TM#12 looked suberb — you did a fine job, especially with all the spot diagram graphics. However, I suspect the labels on the computer printouts confused you. On them, the EFL is taken as negative. Thus focusing away from the mirror, or outside focus, is shown as negative, and toward the mirror is positive.

However, to be consistent with the article, F is positve, and a negative focal shift is therefore going inside paraxial focus. The upper half of each diagram array should therefore be negative and labeled "inside focus," and the bottom half shown positive, and labeled "outside focus."

Also, the fourth paragraph on page 12 would be a little clearer if it read:

"However, since the Newtonian has a paraboloid as the primary, coma is independent of the stop position. One position does exist for the stop in the Newtonian for which astigmatism vanishes, and this is at one focal length from the primary. But as we have already seen, coma dominates astigmatism for the usual fields of view, and little improvement results by locating the stop at this position. Besides, it would be necessary to enlarge the primary to avoid vignetting off-axis ray bundles, in this case, a poor trade-off."

David Stoltzmann

—Oops.

Caveat Emptor

Dear Fellow Amateur Astronomer:

In July of 1980, I went to a star party with my 12.5" telescope. It was a night of excellent seeing and transparency. I had been contemplating a larger telescope for some time, but when my 12.5 was out-resolved by a 14" and a 16.5", I really began to "heat up". The views in the 16.5" were nothing short of spectacular. I came home with a severe case of "aperture fever."

Scraping together money from every source, including my Memorial Telescope Fund and the sale of my 12.5", I hastened to plunk down a deposit. It all sounds so easy. You just give them the money and along comes a beautiful telescope, finely crafted and of excellent quality. How I wish it were true.

If I had heard the tale of woe that I am telling now a year ago, I would have found it unbelieveable. I would still like to think that the telescope that I finally received is a fluke, but the incredibly shoddy workmanship and the extremely poor optical quality. . . .

I hope that my misfortune can serve as a lesson to others who may be contemplating the purchase of a large commercially-made scope.

The most frustrating problems I encountered were the delays and excuses. Repeatedly, I was told that they couldn't go any further because they didn't have one part of another. Finally, the only thing left for them to acquire was the glass.

After four months of listening to excuses, such as, "glass takes at least three weeks to cool," or, "the glass was shipped to someone else by mistake," or, "the glass was a bad batch," or "the glass was enroute and the trucking company screwed it up," I took matters in my own hands. I called the supplier. They told me that they had no orders. . . and furthermore, they wouldn't ship anything until a bill which was outstanding for 8 months was paid. They agreed to sell me the glass and I sent a money order and had the glass in a week!

By then I knew that the excuses were calculated to buy time. However, I felt locked in, because the entire price had been paid and I had no means of figuring the mirror or machining the mount myself.

Cash flow is a problem that every small business faces — and I have a certain amount of tolerance for that. But the fact that I was lied to for months did not sit well with me. I have heard that hundreds of people lost money when [company X] went out of business. Somehow that just wasn't very real to me before now.

Anybody can advertise in a magazine and take money to build telescopes. The skills that it takes to build telescopes are not the same skills that it takes to run a business. Many would-be telescope manufactuers have discovered that over the years. Fortunately, most of them were too ethical and cared too much about amateur astronomy. . . .

After sufficiently harassing them, I took delivery on the mount with a 12.5" tube assembly on loan. When I set up the scope at a star party, the gears started popping and tracking very slowly. Everyone was shocked to discover that the worm gear was misaligned and offset from the drive gear, barely making ocntact. Later, I discovered that a spur gear with the wrong shape teeth was also used. I was appalled when a found out that the gear maker had specifically warned . . . not to use that spur gear on my mount!

Finally, after a year of waiting, I got the tube assembly and mirror. I went off to the mountaintop to observe. After setting up and collimating, I put in an eyepiece and discovered to my chagrin that the focal plane was inside the focuser. I had to move the mirror forward 1½" to get an image. Also, the tube was very topheavy and the 'rotating rings' had to be moved 4" to balance the tube.

But, after all this, finally first light! And what did I see? Big round star images that wouldn't focus. With a Ronchi screen, the lines from a star were so bowed they almost looked circular. What a disaster! I took the mirror to an ATM workshop to let their experienced eyes be the judge. The mirror is at least one wave undercorrected. I can't describe the disappointment and grief that I felt. My hopes were so high and the telescope is so bad.

"Take it back," a friend said.

They couldn't give me $40, let alone $4000.

"Make them refigure the mirror," my friend said.

But even I was surprised to find out they don't even know what a Focault test is, let alone how to interpret one. Their optical testing equipment consists of a flashlight with a 130 line Ronchi screen in a dirty little room where they do their optical work. And why give them another chance to screw it up?

"Face the facts," my friend said, "You paid $4000 for a telescope kit that was already assembled improperly."

Well, what is the prospective telescope purchaser to do? Everyone doesn't have the

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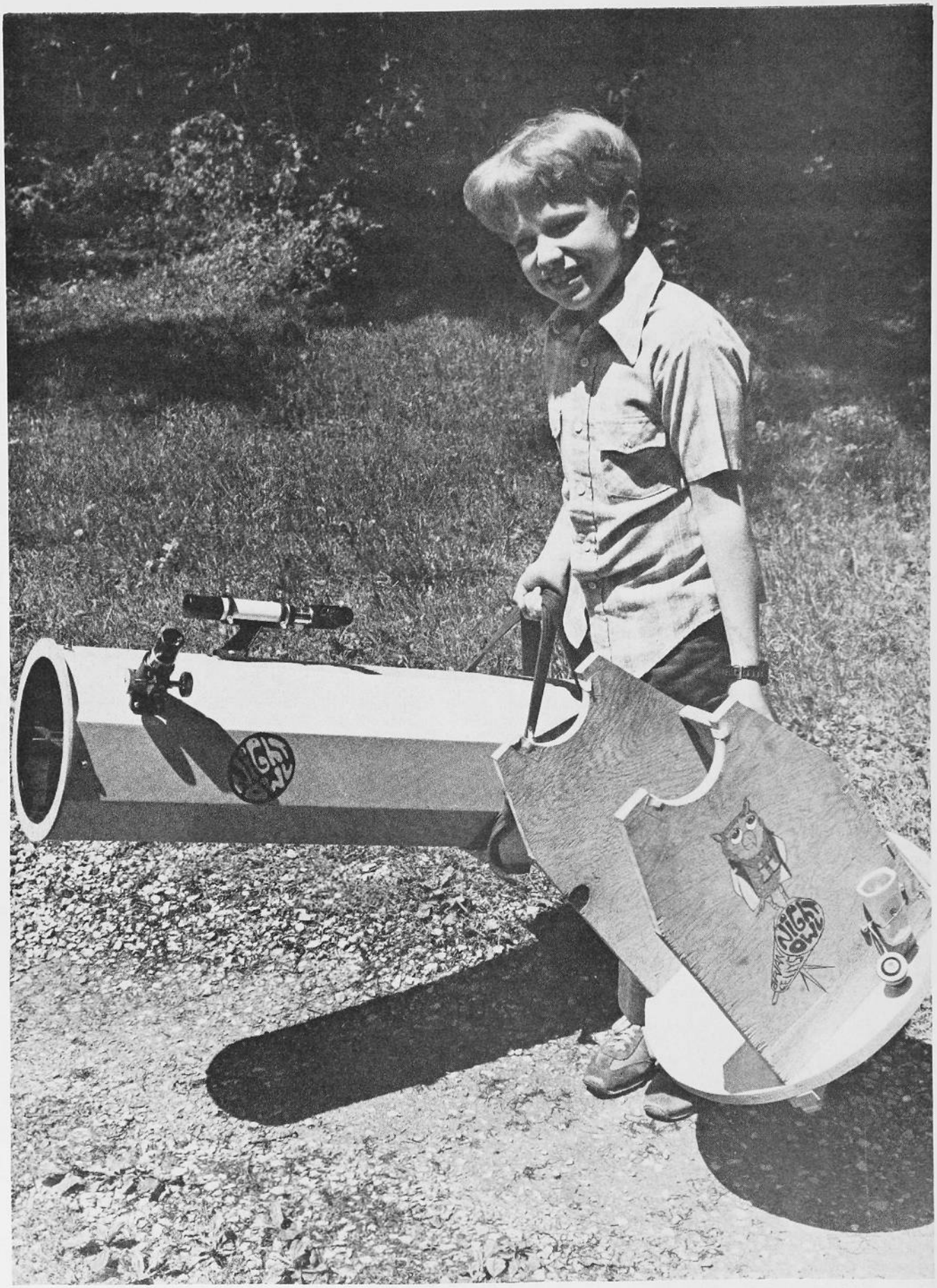


"Night Owl" A Telescope Built with Gatorfoam®

Laminated Foam Panels

I would guess that TMs put more study into their first home-built telescope than into subsequent projects. Later designs will probably be better, not through research, but through experience and the good old process of trial-and-error. Brian's "Night Owl" is an example of study; for the next one, I will rely on experience. At any rate, this first attempt far exceeds our expectations and I think what we learned is well worth passing on.

Brian, my son — just turned 11 — had wanted a telescope for several years. He had come up with half the money and knew that he could get more telescope quicker if "we" built it. While I was only slightly interested in astronomy, it seemed like a nice project and, since I had to come up with the other half of the money, why not? We had borrowed a 6" f/8 from the local high school to see if he was capable of using such a seemingly large instrument. He handled it pretty well except for setting it up. At that point, Brian ordered all the necessary catalogs and got some back issues of TELESCOPE MAKING. We were within a couple of months of being ready to start.

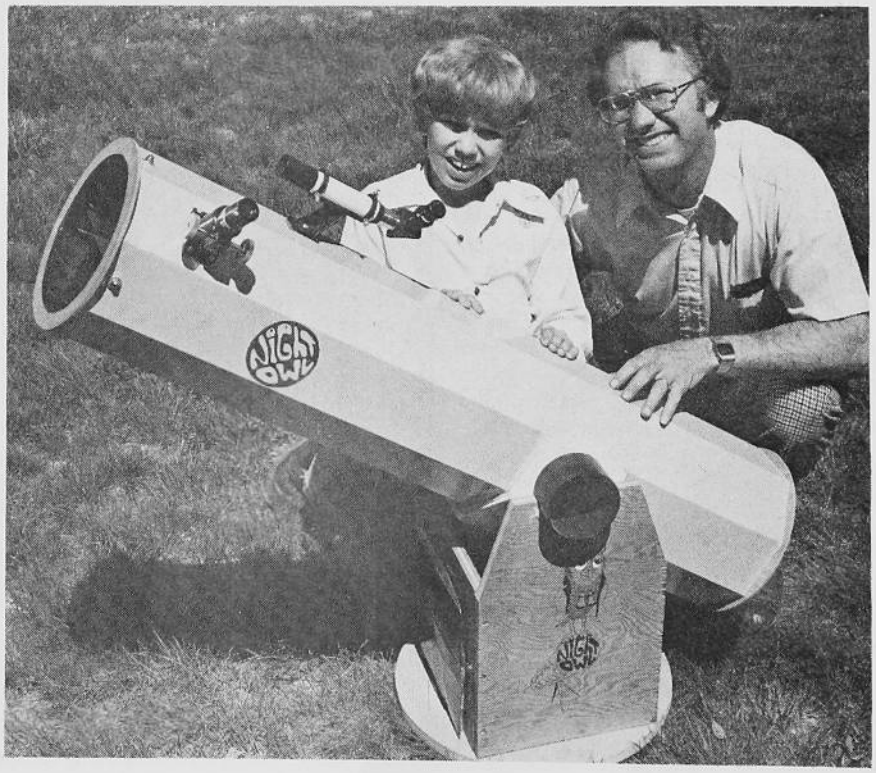
That's when Brian broke his leg. We were visiting an astronomer-friend in Wisconsin, Jim Byard. Jim had originally gotten him interested in astronomy with a gift subsciption to ODYSSEY magazine. Jim let Brian know that now was the time to push for the telescope. He even loaned him the $11.25 that he needed for his half of the parts. What could I say?

It seemed to me that one of the best routes to go would be to build a good scope and put it on a Dobsonian mount. That would allow us to put nearly all the money into the optics and save up for a more sophisticated mount and clock drive later if we wanted to go into photography. So we ordered the parts — an 8" f/6 system and a 20 mm Erfle eyepiece. We bought the mirror, secondary, spider, focuser, finder, and eyepiece, all from Meade. I began designing. Design criteria stressed light weight, low eyepiece height, and durability. I believed if these were met, the scope would be practical for a child.

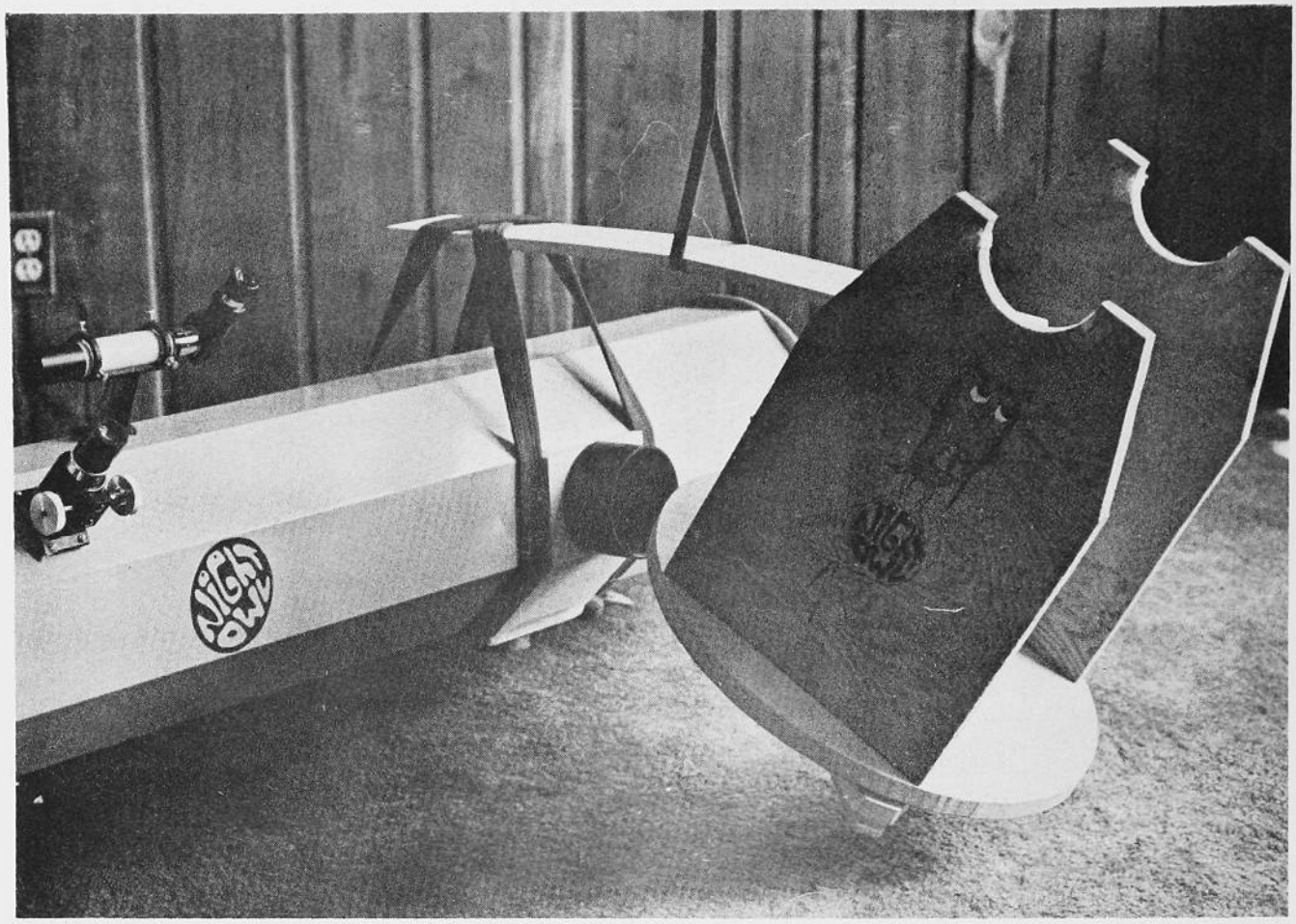
As I read about the Dobsonian design, it was obvious that the weight and balance point of the system were critical. The heavier the scope, the heavier the mount, and the farther up the tube the balance point moves, the higher, heavier, and more unsteady the mount. I wanted the lightest tube possible since saving a pound on the tube could save as much as five pounds in the total weight of the system. Design weight was 35 pounds maximum.

I had never seen anything on using Gatorfoam for telescope tubes, but I had used it for other things. It is primarily used for making portable show booths and signs. It is strong, very insulating, and easy to work with and finish. Also, I had some in stock. I calculated that a tube made from it would weigh only 3 pounds 7 ounces. That sounded good.

The tube took one day to cut and



Brian ready to load up. The Kellys live in a rural area but the nearest clearing is half a mile away. At this point, they have found nearly all the Messier objects visible in the spring evening sky.



The strength of Gatorfoam is shown here. A ½" thick piece 3.5" wide supports both the telescope and the mount of "Night Owl." Deflection is less than ⅜" plywood. Gatorfoam comes in ½", ⅝", ¾", and 1" thicknesses.

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assemble. I used ½" Gatorfoam for a 48" long octagonal tube. 9" I.D. minimum (across the flats) gave a maximum O.D. (across the corners) of a fraction less than 11". Cutting was done with an Exacto knife but a table saw would have been much faster. All the edges were cut with a 22½" angle for perfect fit. Both the inside and outside surfaces (similar to 1/32" birch plywood) must be in contact with one another to get a strong glue joint. Assemble Gatorfoam with white glue — solvent glues cannot be used. Run masking tape along the full length of each joint to hold the tube together while it dries. Glue all joints at one time; the tape holds the job together while you work.

Originally I was going to run small ribs inside the joints for extra strength. This wasn't necessary. We glued on a ring made from ¼" plywood to protect the front end and went on to the next step — painting. I'll never know why we brushed that stuff on. It took three nights of sanding to get it off. Spray is the only way to go when you have a super-smooth surface like Gatorfoam to begin with.

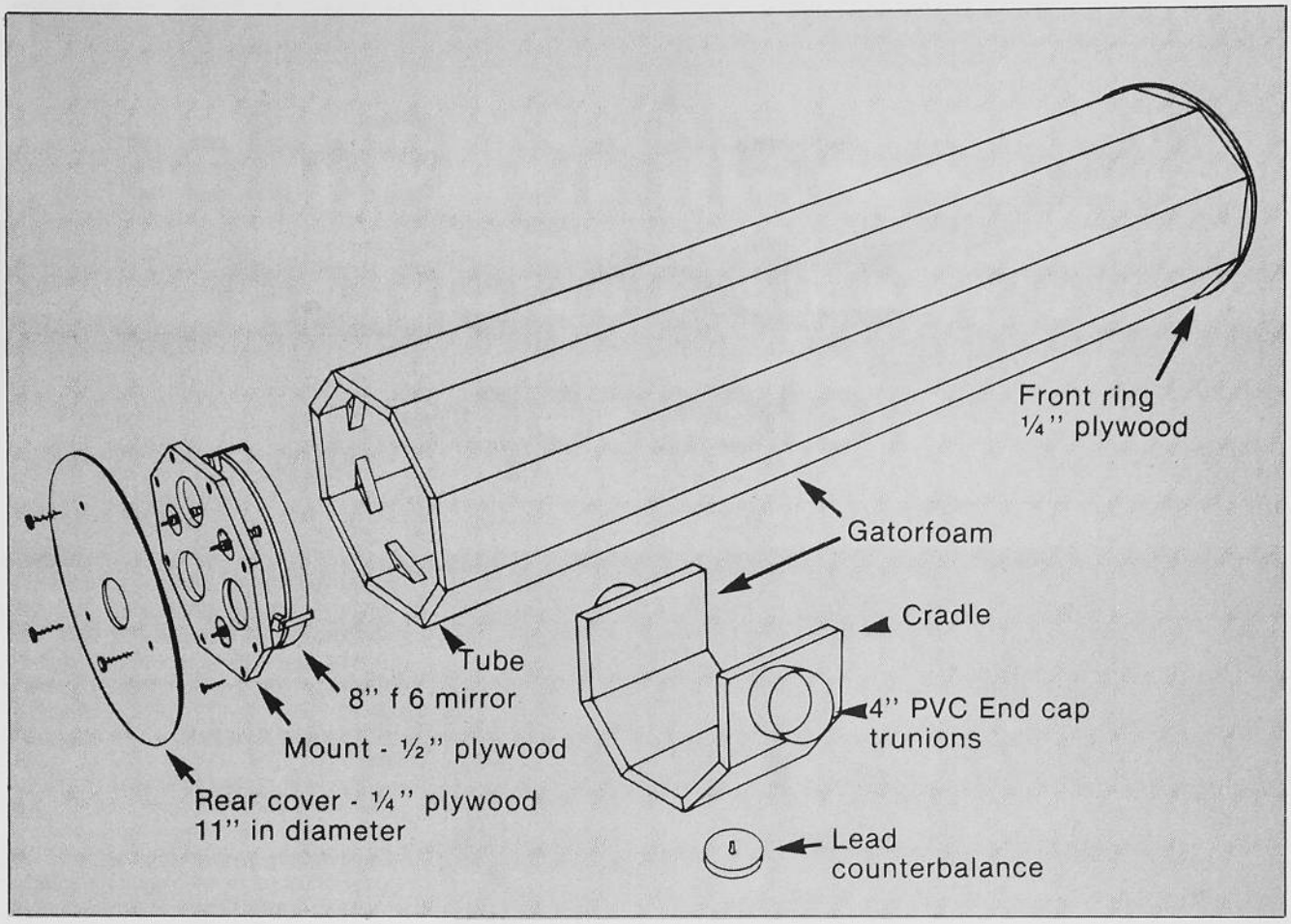
Next came the mirror mount. I wasn't so concerned here with the weight because it is on the "short" end of the balance, and more weight will move the balance point down the tube a bit. Therefore, it is made from ½" plywood and secured with 8 screws, one on each inside corner. We glued small triangles of wood to the inside of the tube at these points.

Working with Gatorfoam rather than a more conventional material didn't present too many problems. I probably should have reinforced the area under the finder scope because the foam can't take the crush of tight mounting bolts. There is enough play in the holes that the finder can be knocked out of line without too much effort. I will correct this in the future. It can be done any of several ways; the easiest is to put a small piece of ⅛" plywood on the inside of the tube and drill through it. I had to make longer spider mounting bolts due to the ½" thickness of the tube and also had to bend the focuser mounting bolts. These were only minor problems and shouldn't present any challenge to someone building their own scope.

The tube turned out to be as strong and light as I had wanted. With both ends protected, it is nearly as tough as plywood and probably more dimensionally stable. It also looks quite a bit better than either plywood or Sonotube. Incidentally, the end rings are more for protection than for stability; Gatorfoam can chip if it's hit hard on the end or any exposed edge. It might not make a good square tube due to the sharp edges.

The mount is typical Dobsonian. All plywood is ¾" and the bottom board is a sink cutout with the Formica already glued on. I realize now that I could have saved some weight by using ½" for the front board, but it will stay as it is. Bearings are Teflon in both the altitude and azimuth axes. The trunnions are 4" PVC pipe end caps. I didn't feel that a complete box was necessary for the tube body since the tube is already very rigid, so we made a "U"-shaped octagonal cradle. It is held on with tape only because we may eventually change mounts. If we hadn't wanted to make the tube convertible, the trunnions could have been mounted directly to it, allowing an even smaller base.

Since the complete unit is light enough to be carried in one trip, I added holders for all the accessories. Coat hanger wire



was brought into play (sorry, I don't have a source; you'll have to find your own). At present, we are taking only one extra eyepiece, a star finder, star chart, and a flashlight with the scope. We will no doubt add more later. We cut a handle into the front board to simplify handling and eliminate the need for extra hardware. A carrying strap for the tube assembly makes everything a one-trip proposition, even for a 10-year-old.

Results? Well, I could get technical, I suppose, but that is secondary. Real results show up in use. The height is right; dozens of kids have used it. Jim (our astronomer friend) is amazed at its ease of use and image quality. And since it weighs less than 30 pounds — complete — Brian can carry it and set it up. But usually he doesn't have to. It seems I am always ready to help him. I even help him use it. I'll probably help him build the equatorial mount he wants sometime. I might even help him with that 17.5" f/4.5. Of course he will have to save up half the money, and that will take him quite a while. Now, if I just raise his allowance....

Robert Kelly
P.O. Box 1446
Columbus, IN 47201

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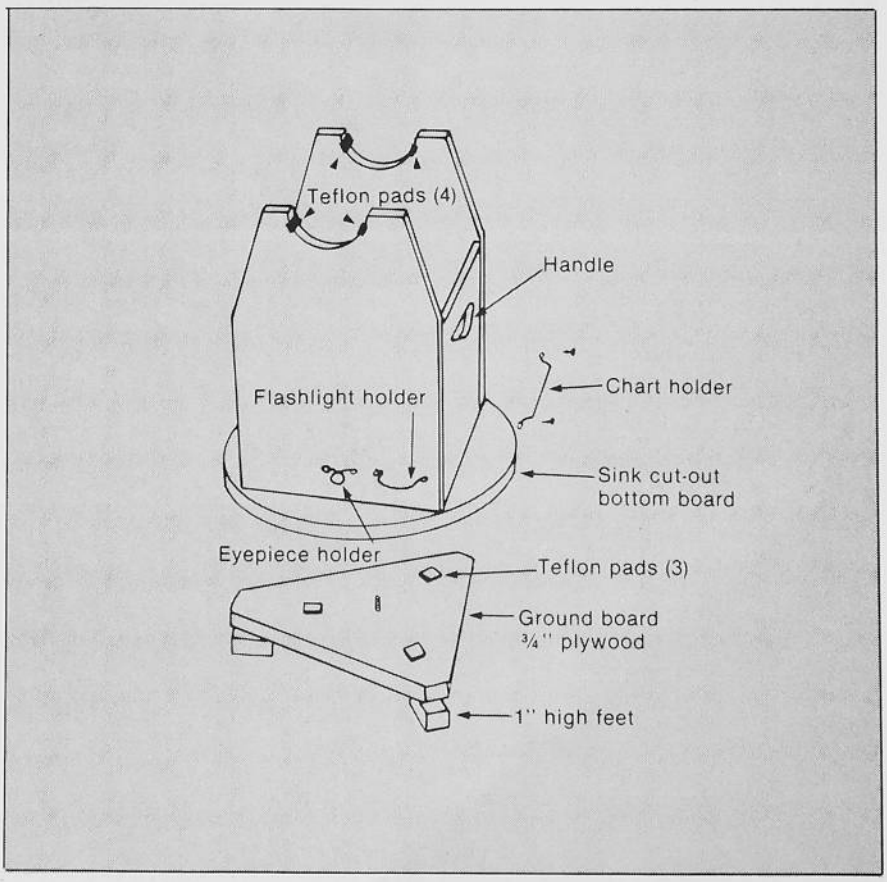
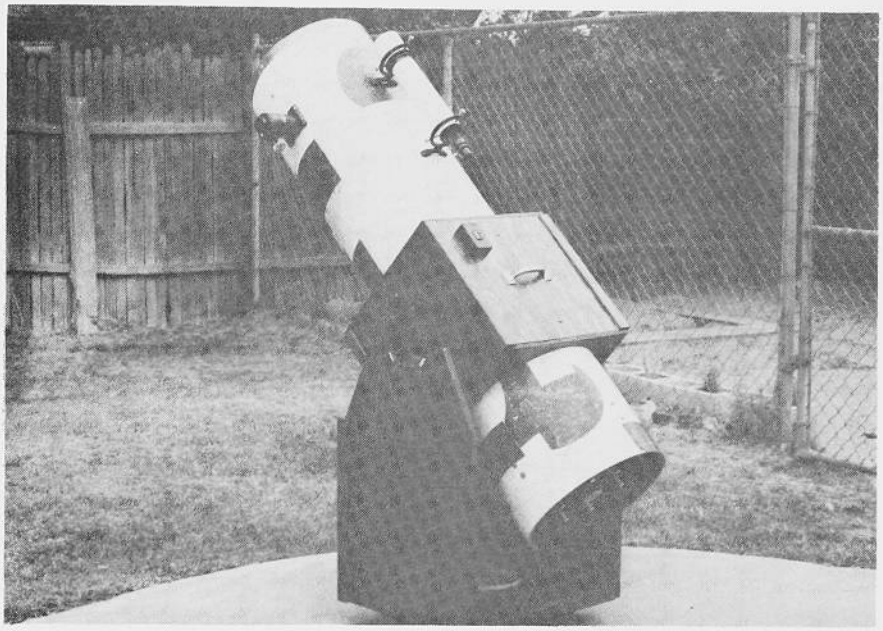
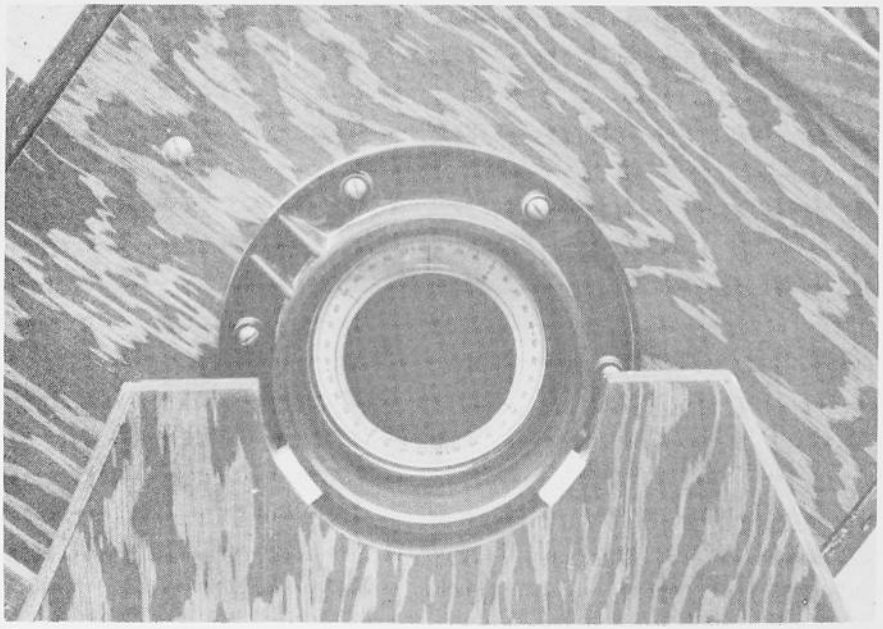


Using Setting Circles on a Dobsonian Telescope





For the past few years I have been interested in astronomy as a hobby. Since I am a restaurant manager, working nights poses a few problems, but the peaceful solitude of observing for a while when I get home gives me a chance to unwind after a night of clanging dishes, country rock music and bar trivia.

My first telescope was a 3-inch refractor. With it, I spent many hours observing the Moon and planets. Occasionally I would drag my wife and kids out of bed to see Venus shimmering in the morning sky or Mercury peeking above a rooftop. Eventually I decided that I needed more aperture, so I sold the refractor and purchased an 8-inch reflector. Up to this point I had made very little contact with anyone "in the know" about astronomy. Of course, I read everything I could get my hands on and, near the end of each month, I'd meet the mailman bringing my ASTRONOMY magazine.

When I had difficulty understanding the celestial coordinate system and couldn't make my setting circles find things for me, I got pretty frustrated. Finally I signed up for a lab course in astronomy at the local community college. The instructor, Dr. Larry Adkins, is a full-fledged amateur astronomer, and he helped me through the confusion of learning about sideral time, right ascension, declination, hour angles, and so on.

During a field trip to Joshua Tree National Monument, where the skies are dark, I had the opportunity to use a 10-inch Dobsonian which I had read about in ASTRONOMY's June-August 1980 issues. I was impressed, to say the least, and observed galaxy after galaxy all night, and by morning had decided to make my own telescope. I'm sure the neighbors were a little skeptical when they saw me unloading plywood and

Alt-Az Program
for use with the TRS-80 pocket computer

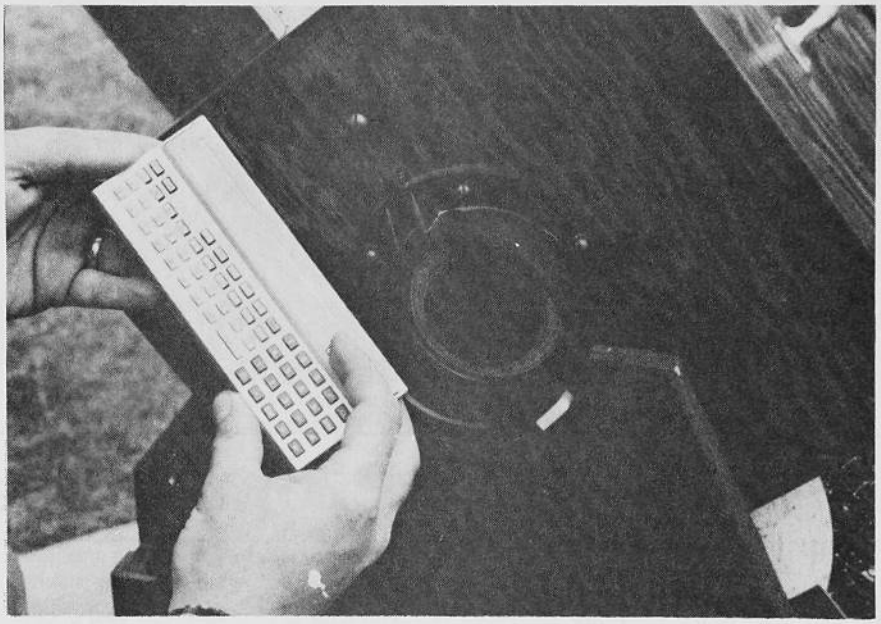
```
10: INPUT "LST?";T, "RIGHT ASCENSION?":R, "DECLINATION":D
20: H = (R - R) *15
30: L=33.7
40: A=ASN((SIN D * SIN L)+(COS D * COS L * COS H))
50: Z=ACS((SIN D — SIN L * SIN A) / (COS L * COS A ))
60: IF R <T GOSUB 80
70: PRINT USING "####.#"; "ALT=":A, "AZM=";Z
80: LET Z=360-Z: RETURN
```

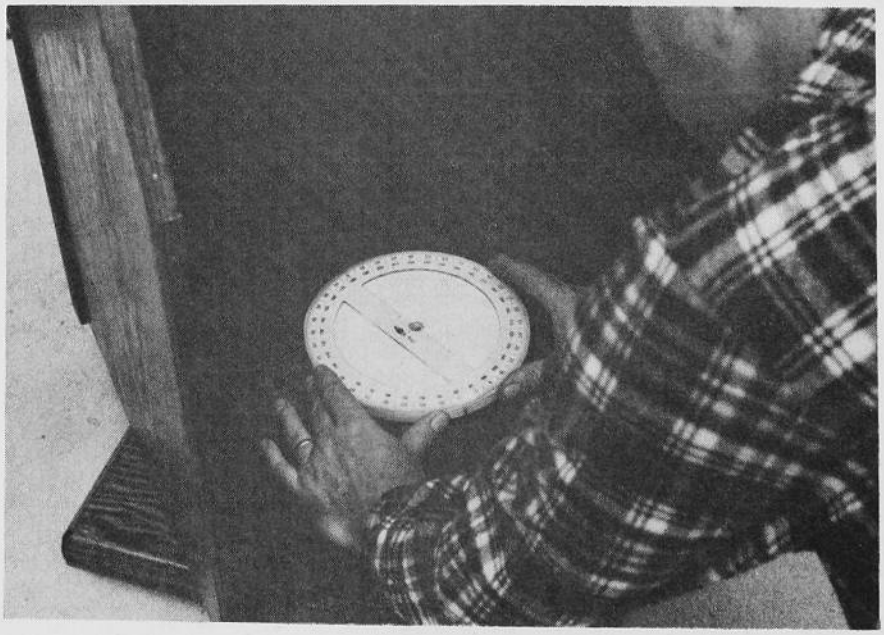
Sonotube out of my camper. The only people who really believed it would work were all the kids on the block.

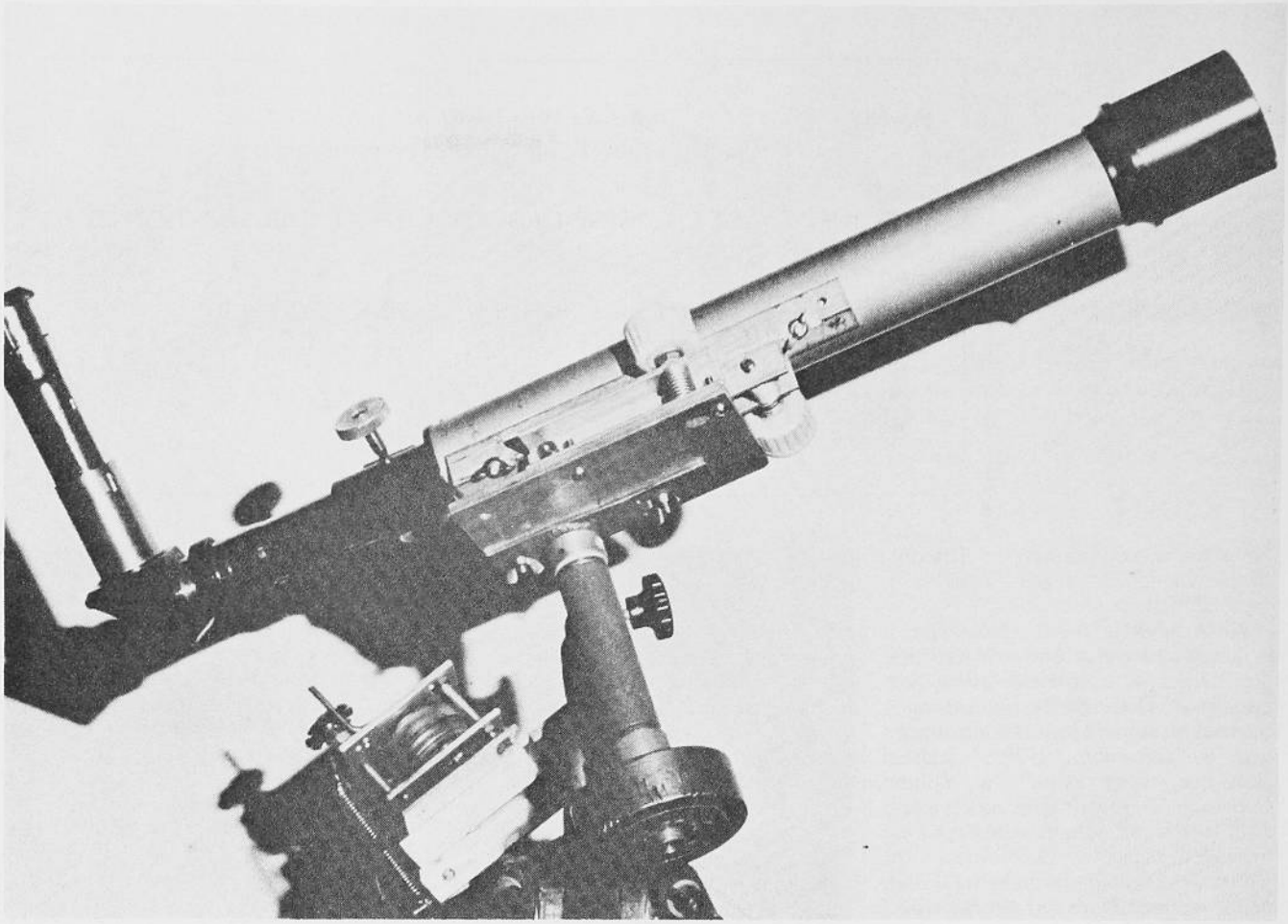
While working on the telescope, it occurred to me that I had read an article about celestial coordinates some time back in ASTRONOMY. I dug through the back issues and sure enough, there it was in December 1978, "Celestial Software, Part Four" by Robert Burnham. After reading the article again, I went to the college and wrote a program in BASIC using the two formulas for altitude and azimuth given in the article, and it worked! Now all I needed was a way to measure altitude and azimuth on my Dobsonian. The answer came to me in a hardware store — a roofer's level, used to measure the angle of a roof. I bought one and installed it in the middle of the side bearing. Then I bought an 8-inch diameter, 360 degree plastic protractor and glued it to a wooden disk. By mounting the disc over the center bolt, I could read off the azimuth the telescope was pointing at. After selling the 8-inch reflector and purchasing a pocket micro-computer, I entered the program in it. It crunches out the numbers in about eight seconds, returning altitude and azimuth to a tenth of a degree from RA, Dec, and siderial time.

Finally the day came when I picked up my mirror (it took 20 weeks because they were on back order), and the telescope was complete. As I anxiously drove home that night, the clouds rolled in, and I had to wait another four nights before it was clear. On the first clear night, I set up in the back yard (set up time — 5 minutes). Vega was high in the sky, so I entered the coordinates — Crunch! Altitude, 81; Azimuth, 56. I moved the telescope around and raised it up. Vega looked so good!

Stephen K. Kysor
11782 Blue Jay Lane
Garden Grove, CA 92641







An H-Alpha Prominence Telescope

I became enthralled by the solar prominences of the February 26, 1979 total eclipse. I just had to see them again. My next chance would have been the February 1980 eclipse, but three minutes of totality in Kenya would have cost about $2400. Paying $800 per minute to look at prominences is slightly ridiculous, so I decided to build a hydrogen-alpha prominence telescope. However, since I knew so little about it, had no experience with it, and would not know how well it worked until some time after the money was spent, I was determined to minimize the cost of my first foray into H-alpha observing.

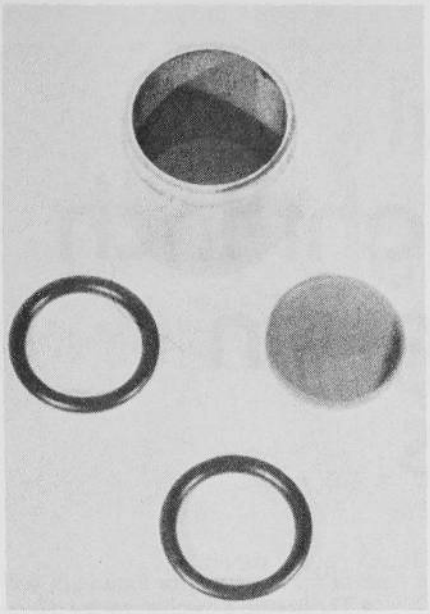
The only suppliers of H-alpha filters that I knew about were Daystar, which I considered prohibitively expensive, and Roger Tuthill. I obtained Tuthill's literature and then telephoned him for some additional information including whether it was possible to buy just the filter element used in his equipment. It was, so I sent off a check for $179. About two weeks later, I had my hydrogen-alpha filter.

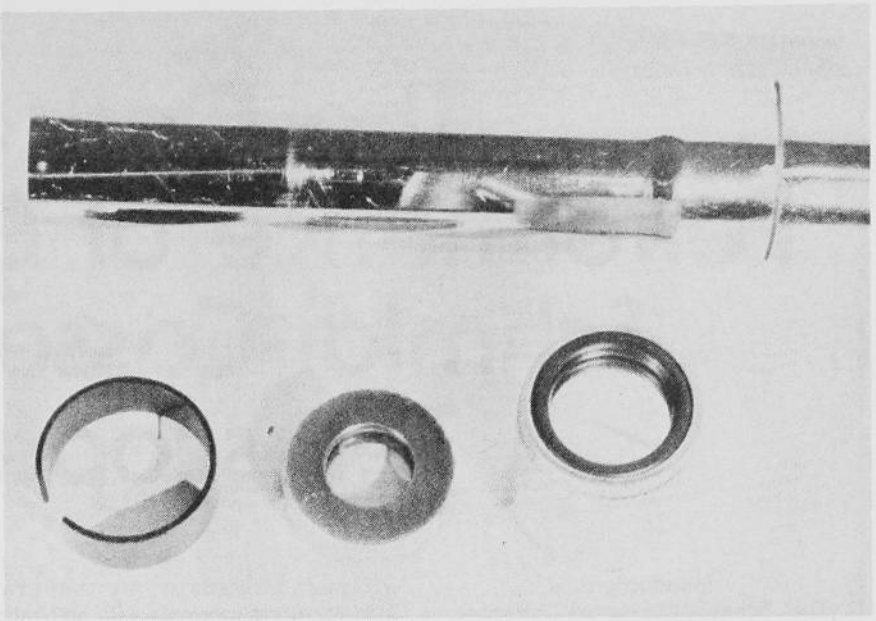
The filter is 1" in diameter and about ⅛" thick. One side has a second-surface gold colored coating, and the other side appears deep red below the glass surface. Accompanying data indicated the filter had a 3 to 4 angstrom passband centered on 6562.8 angstroms at 70° F. Instructions indicated the filter would have to be used in a f/32 or slower light cone for two reasons. First, the filter requires an almost parallel light beam to work properly. The wavelength of the passband depends on the angle that light strikes the filter. Second, a high focal ratio protects the filter from breaking under thermal stress by reducing the amount of solar energy per unit area.

The filter is used with the second surface mirrored side facing the objective. This reflects the bulk of the light back up the telescope tube. However, since the reflecting surface is a second surface, the cover glass gets heated by absorption of some of the energy passing through it.

I mounted my filter in a 1.25" long length of 1" electrical conduit. One inch conduit is actually about 1.032" ID and about 1.125" OD. This allows a little space around the filter for expansion. At the suggestion of Tuthill, I hold the filter in place in the conduit with an O-ring on each side. I chose O-rings made of ⅛" OD material to provide sufficient bearing surface. The closest size available was slightly larger than the conduit ID. I turned them down slightly by stretching them over the chuck of my ¼" electric drill, clamping the drill in a vise, and then gently pressing a fine file against the O-ring on a spinning chuck. I set the filter approximately square to the optical axis by seating the conduit, O-rings, and filter against a flat surface. This method, of course, assumes that the end of the conduit is cut squarely.

A tilting mechanism to fine tune the filter for use at temperatures above 70° F might be desirable although I have found it unnecessary. I have successfully used my filter over a temperture range of from





60° to 90° F with no problems.

I wrapped several turns of duct tape around the conduit until it was a good slip fit into a 6″ long by 1.25″ diameter sink trap extension. Between the filter and the end of the sink trap extension closest to the objective, I inserted a mounted Barlow lens. The Barlow controls the final f/ratio of the light cone passing through the filter.

To improve image contrast, an oculting disc should be placed in the focal plane between the filter and the eyepiece. In my case, a penny (i.e., a one-cent piece) provides a suitable disc. I drilled a carefully centered hole in a penny and inserted a bolt which could be chucked into my drill held in the vise. I used a file to turn a sharp edge on the penny.

Since the best part of the eyepiece field is in the center, I place the edge of the occulting disc approximately in the center of the field. It is held in the focal plane of a ⅞″ focal length Brandon eyepiece by pinching its edge between the base of the threaded eyepiece filter holder and a screw-in filter cell obtained from a filter. I filed off one side of the penny to fit the ID of the eyepiece barrel.

The diameter of the penny sets the maximum diameter of the final image of the Sun in the focal plane of the eyepiece. Since the penny is about 0.75″ in diameter, the optimum focal length for the system is about 83″. The telescope is a 2″ refractor with a 24″ focal length. For an 83″ final focal length, the final focal ratio is f/41.5 through the filter. This means the Barlow should be 3.5 power. The telescope provides about 95 power with the ⅞″ eyepiece.

To observe prominences, I place the solar disc behind the occulting disc. This allows me to scan more than 90° of the Sun's limb at one time. By rotating the filter and eyepiece assembly 90° at a time and repositioning the Sun behind the disc, I can scan the entire limb.

Sometimes with my setup there is a faint ghost image of the Sun slightly offset from the true image caused by a slight tilt in the filter. To eliminate the ghost from my system, I first orient the occulting disc relative to the filter so that the ghost image is shifted onto the true image of the Sun along the portion of the limb I am looking at. Then I rotate the eyepiece and filter together as I scan the limb to keep the ghost out of view.

A clock-driven equatorial mount with coarse slow motions on both axes is helpful for observing. I made the slow motions by copying the mechanism used to set elevation and windage on some rifle scopes. Two 4″ long by .75″ aluminum angles overlap to form a U-channel. I inserted a pivot bolt through the overlapping angles at one end, and at the other end, drilled holes through the faces of the angles forming the sides of the "U". One hole was threaded. A ¼″-20 bolt was inserted through the unthreaded hole, through a stiff spring, and threaded into the threaded hole. Turning the bolt causes the angle between the sides of the "U" to slowly change.

A second version of the above is mounted on the first so that its scissor action is at right angles to the first. This mechanism is placed between the telescope tube and the telescope mounting plate. The ½° needed to scan the limb of the Sun is quickly and accurately made by turning knobs on the bolts.

The performance of the filter with my 2″ telescope is fantastic. Although good sky transparency is needed for best performance, it does not have to be as good as I first thought it might. Atmospheric seeing effects seem strange. Even when the limb of the Sun boils madly, the prominences appear very steady. Fine detail in the prominences is easily visible. Most prominences visible through the telescope seem to just sit there or change very slowly. But some don't. It is exciting to watch an apparently small section of the Sun, actually many Earth diameters, explosively blow away over a period of 10 to 30 minutes. If you want to draw a crowd at a daytime astronomical gathering, bring a prom scope. Most other telescopes seem to be good only for looking at during the day.

I have tried using my filter assembly on a 6″ f/15 refractor giving about f/50 through the filter. Although I had a good view, after several minutes of observing the filter assembly became quite warm. No damage was done, but I had never noticed any heating with the 2″ telescope. Of course a 6″ collects nine times as much energy as the 2″. However, with the 2″, the bulk of the light collected by the objective, even when the image is off center by half a solar diameter, falls on the mirror surface of the filter and is reflected back up the telescope tube. With the 6″, the light bundle is larger and a large part of it is impinges on the structure around the filter. This is absorbed and causes the heating. Anyone attempting to use this filter system on a telescope much larger than my 2″ will have to deal with this problem.

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The Optical Performance of Eight-Inch Schmidt-Cassegrain Telescopes

Introduction

The Schmidt-Cassegrain telescope, especially the 8″ (200 mm) aperture design, has become very popular among amateur astronomers in recent years. In this article we analyze the optical performance of the Schmidt-Cassegrain by means of optical ray tracing. This yields considerable insight into both the on-axis and off-axis optical performance.

We also investigate the influence of several parameters on the image quality, such as varying the aspheric correction of the Schmidt plate and the optical centration of the system. In all calculations, we assume that the figuring of all the optical surfaces corresponds exactly with its mathematically prescribed shapes.

The Schmidt-Cassegrain telescope is offered nowadays by several manufacturers, normally with an f/ratio of 10 or 12. In this article we do not comment on the quality of any trademark compared with other trademarks, nor do we discuss the mechanical performance of these instruments. We concentrate only on the optical system. The conclusions at the end of this article are of a general nature and may be applied to all brands that are offered on the market at present.

Different Types of Focus Mechanisms

The designs that are offered at present differ primarily in the focusing mechanism. The systems can be classified into two groups:

- Those in which focusing is accomplished by moving the primary mirror (in short: mirror focusing); and
- Those with a mechanism for moving the eyepiece by means of a rack and pinion mount or helical thread tube (in short: eyepiece focusing).

The first mentioned systems are offered, for instance, by Celestron's C-8, Criterion's Dynamax, and Meade's 2000. The second type is manufactured by Lichtenknecker Optics of Belgium and others.

Mirror focusing requires a precise fit between a tube that carries the mirror (usually attached with an adhesive) and the tube that supports the mirror assembly. If the fit is less than perfect, a displacement of the image can be seen during focusing. We shall discuss the influence of image displacement on image quality. It must be emphasized

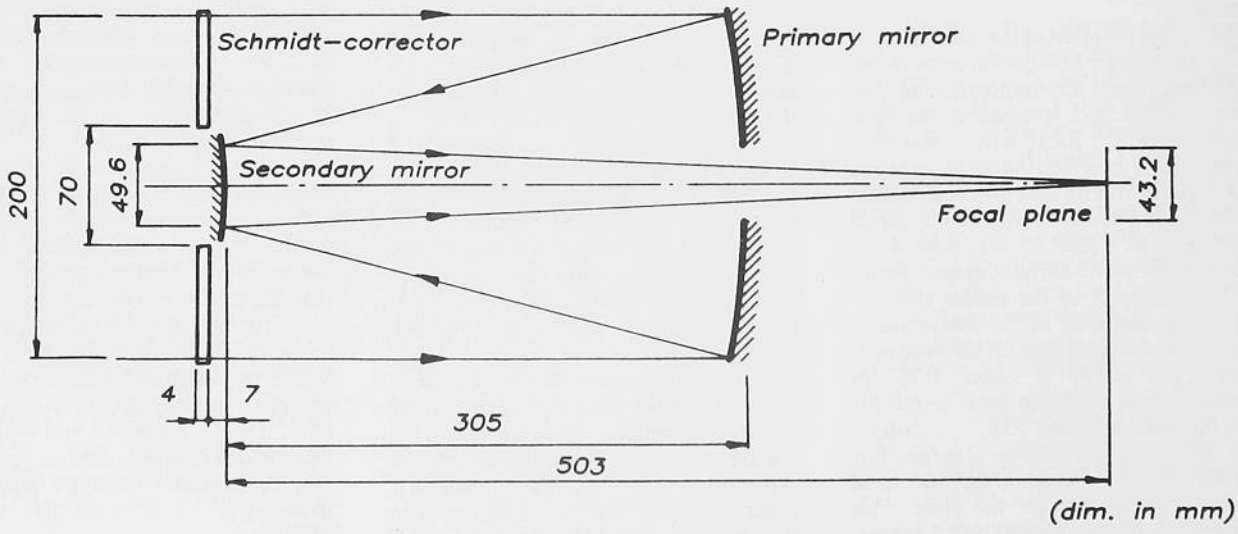

Fig 1. Main dimensions of a well known 8–inch F/10 Schmidt–Cassegrain telescope

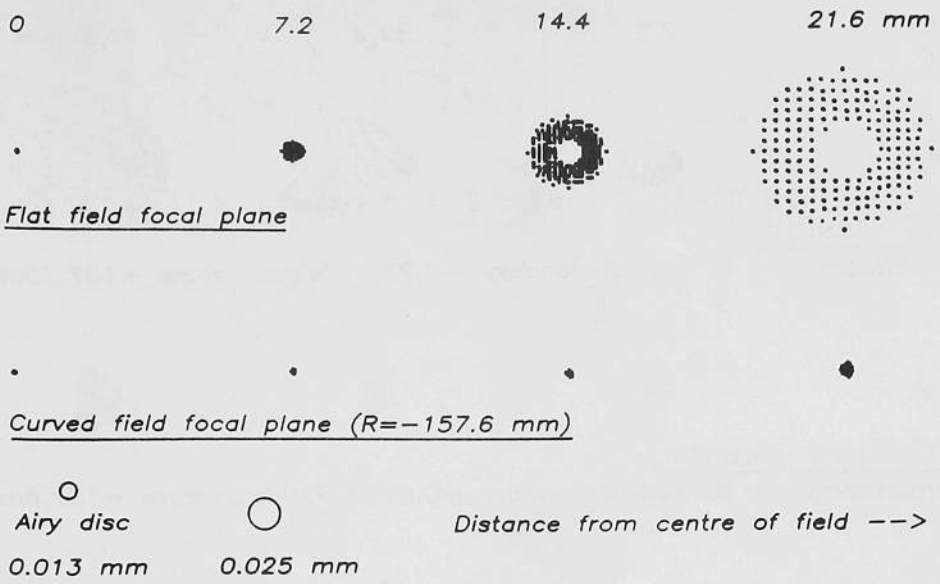

Fig 2. Spotdiagrams for the optimized design for the flat field and curved field focal planes

that the manufacturers of the mirror focusing systems have deliberately chosen this mirror focusing system. Such a focusing mechanism extends the application of the instrument considerably, because it allows focusing on terrestrial objects at very short distances. This is important especially for nature enthusiasts. Observations of birds, flowers and insects — especially at short range — with an eight inch telescope gives very detailed and highly impressive images.

With an eyepiece focusing mechanism, the observation of near objects is possible, but at a considerable loss of image sharpness. We examine, among other things, the image sharpness for short distances to the object both by mirror focusing and by eyepiece focusing.

Results of Ray Tracing

The optical system of the Schmidt-Cassegrain consists of 1) a Schmidt corrector which suppresses the spherical aberration of the primary mirror, 2) a spherical primary mirror, and 3) an aspheric secondary mirror. For optical ray tracing, we need the radii of the optical surfaces, distances between optical elements, and so on. Unfortunately, the manufacturers of Schmidt-Cassegrain systems do not reveal complete optical data for their instruments. It is possible, however, to measure these data from an existing instrument. Figure 1 shows the main dimensions of a well-known f/10 instrument when the system is focused on infinity. The secondary magnification — that is, the ratio of the focal length of the system to the focal length of the primary mirror — appears to be approximately 5. Other brands that are offered on the market have roughly the same dimensions.

Many combinations of the corrector and secondary mirror can give good image sharpness on the optical axis. It is possible, for instance, to use a relatively strong Schmidt corrector combined with a strongly aspheric secondary mirror. However, certain combinations of weak Schmidt corrector and weak aspheric secondary mirror also produce a sharp on-axis image. If only good image sharpness in the center of the field mattered, the combination of corrector and secondary would remain

Table 1. Optical data for an eight inch f/10 Schmidt-Cassegrain telescope

Radius first corrector	flat
Thickness corrector	approx. 4 mm
Corrector glass	Schott BK-7
Radius second corrector surface	-45,029 mm, deformed
Neutral zone of corrector	86.6%
Deformation, relative power	83.42%
Distance corrector to primary mirror	312.5 mm
Radius of curvature primary mirror	-817.465 mm
Distance primary-secondary mirror	-305.5 mm
Radius of curvature secondary mirror	-253.75 mm
Deformation secondary mirror (sphere = 0; parabola = -1)	-0.8957
Distance secondary mirror - focal plane	503.09 mm
Radius optimal curved focal plane	-157.6 mm
Effective focal length	2027.0 mm

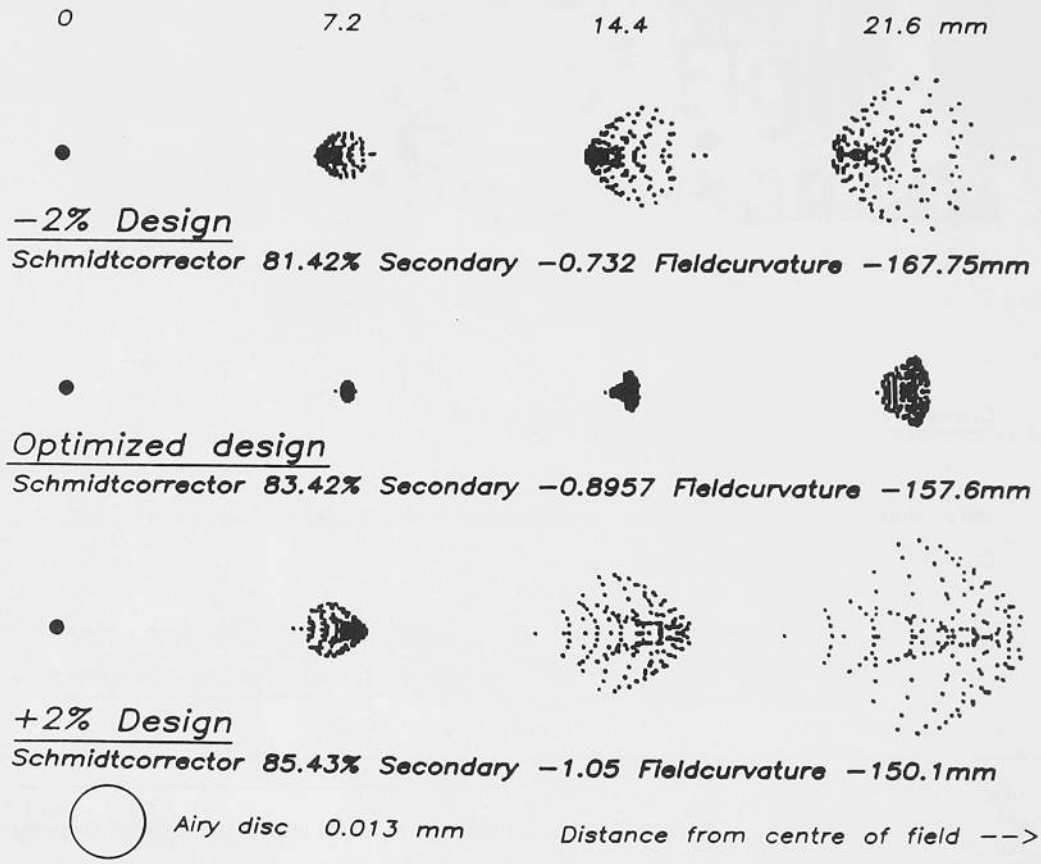

Fig 3. Spotdiagrams for two different designs compared with the optimized design
(mind the different scale in comparison with fig. 2)

undetermined.

To determine the shapes of the Schmidt corrector and the secondary mirror discussed for this article, we assumed that the designers of such an instrument would have chosen a combination that, while avoiding spherical aberration, minimizes the effects of coma and astigmatism over the focal plane. In exactly the same way they must have, we arrived at the optimum design. We analyzed numerous combinations with the help of our computer program.

We demonstrated that for optimum performance, the Schmidt corrector must be chosen with such power that the spherical aberration of the primary mirror is only partially corrected. More exactly: the Schmidt corrector must have a power of 83.42% of the corrector that would be needed for a full correction of the spherical aberration of the primary mirror. According to our analysis, this value must be held within close tolerances, because a relatively small deviation gives unacceptable off-axis coma.

Another choice we made was the form of the corrector plate. In the literature, several types of Schmidt correctors with different shapes have been described. For our calculations we chose the corrector with the minimum color deviation. The neutral zone of this plate is situated at 86.6% from the radius. Table 1 gives the formula of the optimized design we derived.

The upper row of spot diagrams in figure 2 shows the images from the optimized design for a flat focal plane (for instance, a photographic negative) in comparison with the diameter of the Airy disk (0.013 mm) and a circle with a diameter of 0.025 mm (0.001 inch), a figure often used as the maximum allowable spread of light, or blur spot, for photography. The diameter of the focal plane shown is 43.2 mm, the diagonal of a 24 x 36 mm negative, and the maximum distance from the optical axis is 21.6 mm.

On axis, the spread of rays remains well within the Airy disk circle which means that the image is diffraction limited at that place. However, at a distance of approximately 10 mm from the optical axis, the spread of spots exceeds a 0.025 mm circle, which restricts the photographically useful field to a radius of 10 mm if this criterion is accepted. This corresponds to an object having an apparent diameter of the Full Moon. Outside this circle, the spot diagram swells up considerably, causing fuzziness at the edge of the field.

A closer look at the origin of the off-axis spread of the spots reveals that this is caused by curvature of field, which is mainly a result of the strongly curved secondary mirror. In order to see that the sharpest image is formed on a curved focal plane, refer to the lower row in figure 2. These spot-diagrams are given for the focal plane curved to a radius of -157.6 mm. If you could use curved film in

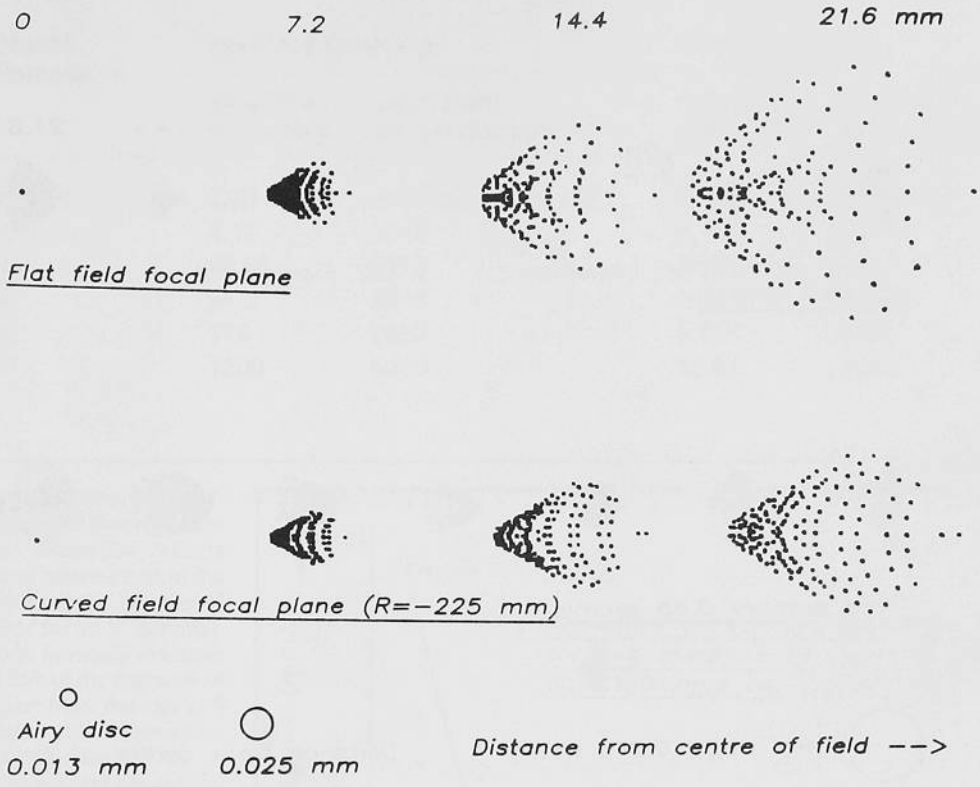

Fig 4. Spotdiagrams for the design with spherical mirrors for the flat field and curved field focal planes

your camera, a diffraction limited image could be obtained over the entire focal plane.

There are several methods to suppress the curvature of field in a Schmidt-Cassegrain system. However, if these methods are employed, other disadvantages are introduced and cancel the advantages of the existing, simple design. As far as we know, only one manufacturer of Schmidt-Cassegrain telescopes supplies a field flattening lens to remove the curvature of field when the instrument is used for photography. The focal length of the system is then increased approximately 50% — a decided disadvantage.

To check the color correction of the Schmidt-Cassegrain, we traced blue, yellow and red light through the system. The results showed us that there is hardly any difference in performance, so that the system can be considered almost perfectly achromatic.

Finally, we examined the effect of varying the combination of the Schmidt corrector and the secondary mirror on the image quality. Figure 3 shows the ray tracing results when the power of the Schmidt corrector is varied 2% over and under the optimized design and a matched secondary mirror is chosen. In making any comparison, note that the scale is larger than the scale in figure 2.

Of course, the image sharpness on the optical axis proves to be the same as in the optimum design. However, the off-axis image quality suffers from coma when a different design is applied. In manufacturing, deviations from the optimum corrector plate and the primary mirror are corrected by local figuring of the secondary mirror. In this manner, the system can be freed from spherical aberration, and a sharp image axial image obtained. The off-axis image quality, however, as it appears from the foregoing, does not remain optimal.

A Schmidt-Cassegrain Telescope with Two Spherical Mirrors

Recently it was brought to our attention that some manufacturers of Schmidt-Cassegrain telescopes (most probably in order to reduce the cost of manufacture) leave the secondary mirror a sphere instead of making it aspheric. With a matching Schmidt corrector, spherical aberration can be avoided, so that the axial sharpness will not be diminished compared to the optimum design. However, a system with two spherical mirrors has strong off-axis coma, as clearly shown in figure 4.

Misalignment of the Primary Mirror

If a mirror focusing system is used, and there is appreciable play between the mirror drawtube and the tube that it rides on, pressure caused by an eccentric focusing knob will cause a deviation of the optical axis of the mirror. This play is noticeable because an image displacement occurs when the primary mirror is moved ("shifting"). This can sometimes be annoying when the object

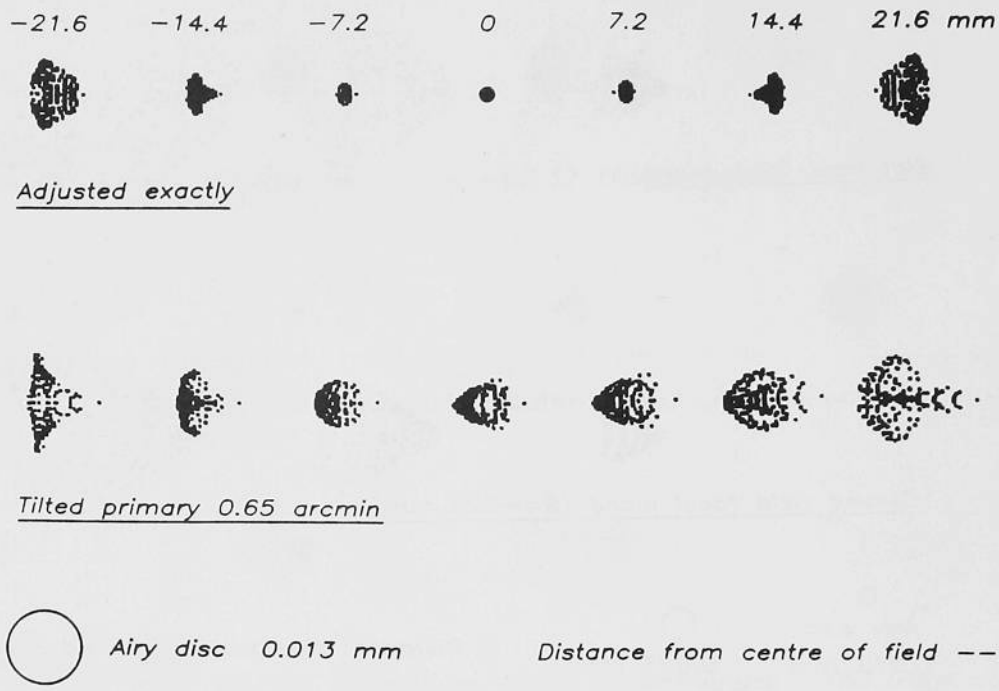

Fig 5. Spotdiagrams for the optimized design with a tilted primary in comparison with an exactly adjusted primary

(mind the different scale in comparison with fig. 2)

under observation disappears from the field. Apart from this effect, what effect does this displacement have on the image quality? We investigated this problem with the computer program. To estimate the magnitude of the shift, we consulted the manual of one brand. The following statement is made: "For this focus mechanism an image displacement of about one third of the field is normal at high power." When this is calculated, it corresponds with an image displacement of approximately 1.5 mm, or a maximum misalignment of the primary mirror by 0.65 minutes of arc. In figure 5, we compare this situation with that of an exactly aligned primary mirror. It appears that with this deviation of the primary mirror, coma occurs across the entire focal plane. This coma is so small that the image remains diffraction-limited over practically the whole field. It appears that if the shift does not exceed this limit, image sharpness will not suffer from an image displacement.

Focusing on Nearby Objects

The ability to focus on a nearby object is of special interest for a certain category of users. The optical system, however, was designed to deliver its highest sharpness when focused on infinity. How is the image quality affected when the system is focused on objects at a relatively short distance? We investigated this problem both for mirror focusing and eypiece focusing systems on objects between infinity and 10 meters. Figure 6 graphs the diameter of the axial spot diagrams.

We draw the following conclusions: 1) for object distances less than 20 meters, the image sharpness for the instrument with eypiece focusing is less than with mirror focusing; and 2) at short object distances, the image sharpness for a mirror focusing system also diminishes because the diameter of the spot diagram swells considerably.

Table 2 shows that if an instrument with eyepiece focusing is used for nearby observations, some other disadvantages are introduced. Both the focal length and the eyepiece movement increase enormously, and furthermore, the light cone coming from the secondary mirror has a diameter larger than the hole in the primary mirror, which results in vignetting and loss of light. For observations of short distance objects, it appears that an instrument with a mirror focusing mechanism is preferable.

Table 2. Eyepiece focusing compared with mirror focusing

Object distance	eyepiece focusing		mirror focusing	
	eyepiece movement	equivalent image distance	mirror movement	equivalent image distance
infinity	0.00 mm	2027 mm	0.00 mm	2027 mm
1000 m	4.12	2040	0.163	2027
100	42.93	2178	1.675	2027
50	94.5	2336	3.354	2029
30	175	2680	5.598	2031
10	1200	5930	16.87	2037

The Obstruction of the Entrance Pupil

A ray tracing calculation does not take into account the diffraction effects caused by the central obstruction of the system. The diameter of the housing of the secondary mirror for an 8″ Schmidt-Cassegrain telescope normally amounts to between 30 and 35% of the diameter of the entry pupil. Apart from the loss of 9 to 12% of the light, this obstruction degrades image contrast. This is noticeable when high powers are applied — for instance, on lunar and planetary details — in comparison with nonobstructed optics with the same aperture.

This diffraction effect does not play a significant role when the instrument is used for photography of stars and nebulae, nor does it affect terrestrial photography because the effect is below the resolving power of the photographic emulsion.

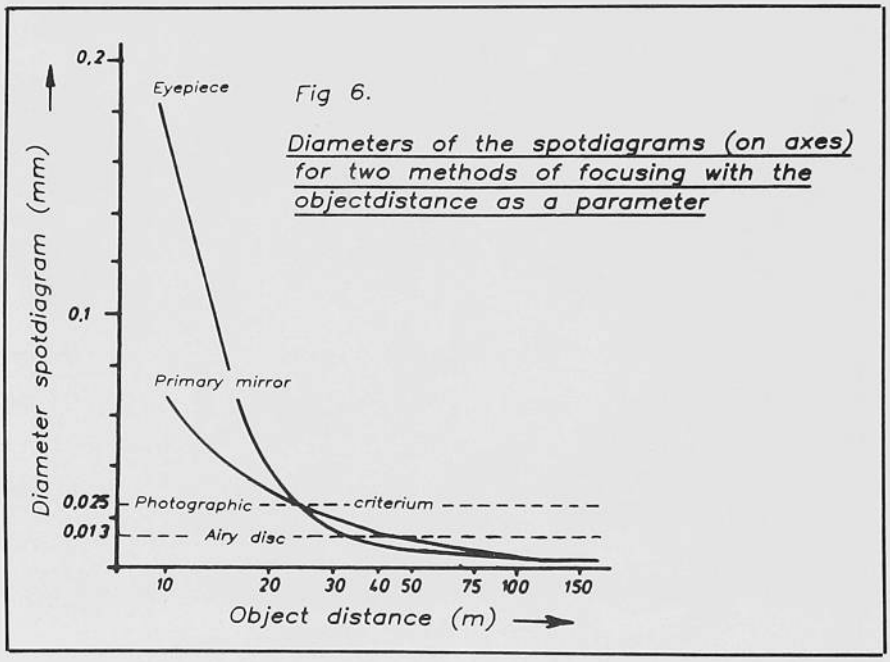

Fig 6.

Diameters of the spotdiagrams (on axes) for two methods of focusing with the objectdistance as a parameter

Summary

The 8″ Schmidt-Cassegrain has several advantages, but, as does every telescope, it also has certain limitations. The advantages are:

- short tube length,
- a closed system, and
- achromatic optics.
- For users interested in focusing on nearby terrestrial objects, a mirror focusing mechanism provides good images.

The limitations can be summarized as follows:

- A relatively strong curvature of field. Over the curved focal plane, a diffraction limited image can be obtained provided the instrument is of the optimized Schmidt plate and secondary mirror combination and the optical parts are manufactured to exacting standards.
- As a result of field curvature, good photographic image sharpness can be realized only for part of the 24 x 36 mm (flat) photo negative. This is true both for celestial and terrestrial photograpy.
- Apart from a loss of light, the obstruction formed by the large secondary mirror causes extra diffraction effects. As a result, the contrast rendition is diminished in comparison with a nonobstructed instrument with the same aperture.
- When a mirror focusing mechanism is used, an image shift can be noticed. As long as the displacement does not exceed a certain limit, no significant decrease in image sharpness occurs.
- When objects are observed at distances less than 20 meters, a reduction of image sharpness occurs.

The above conclusions are of a general nature and may be applied to all brands offered on the market at present.

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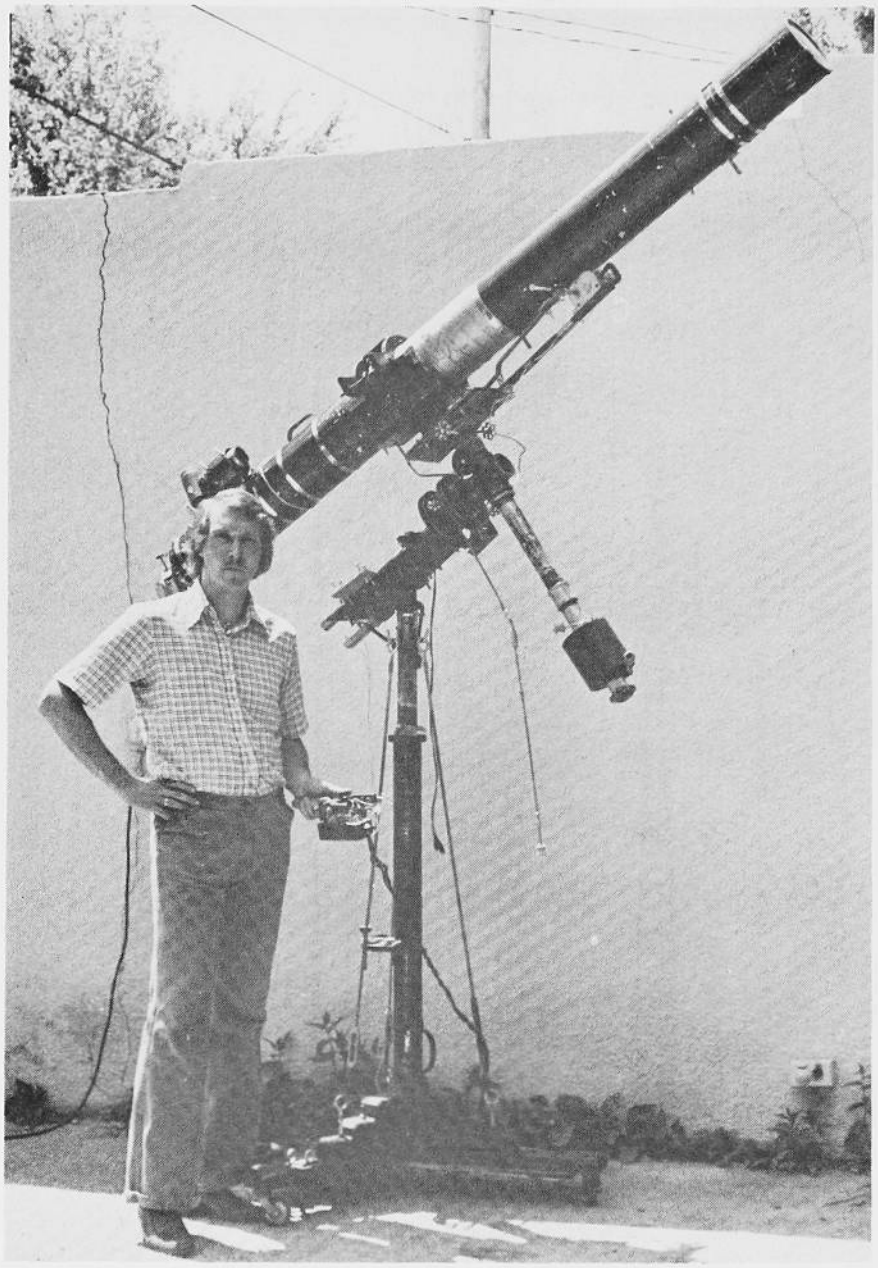


A Poet's Refractor

As a poet and an assistant professor at the University of Denver, I am perhaps as unlikely a candidate for a telescope builder as can be imagined. I know very little about practical physics. I have never machined anything, nor do I own many tools. My tool-hoard comprises a drill, a jigsaw, a tap and die set, and a heavy vise I bought at a garage sale. Since my teens, I had observed through one small, commercially-built telescope after another — most recently a fairly good 8" catadioptric. And yet I longed for an instrument which could split the double-double in Lyra the way I had always read it could be split — into four widespread brilliances. I also wanted to see Jupiter's zebra stripes, not indistinct equatorial fuzzes, and so I set out to build a refracting telescope. Like much modern poetry, it is not beautiful, but it is interesting.

I bought the 6" f/15 Jaegers objective and tubes through an ad from a party who reneged on paying the shipping charges as we had agreed. I first tried out the optics by lashing the tube to a picnic bench and pointing the assembly at some volleyballers in a park. The contrast was magnificent! Heartened, I set to work building the mount in order to star test the telescope.

The portable pier is the body of an enormous fan of the sort used to cool auditoriums. I found it some years ago in a Philadephia gutter where it had been discarded after having been toppled and mangled in a bar-fight. To the original fan base I attached two-by-fours to prevent the whole from tipping, and stabilizing struts made of threaded ⅜" rods, rod couplers, and eyebolts to make the pier more rigid.

A pipe telescopes into the pier, and can be adjusted to give the telescope a comfortable height. At the end of this pipe is an adjustable head — a small steel plate to which is bolted a large rectangular steel table. I bolted self-adjusting 1.188" pillow blocks to this plate to house the polar axle, which turns in them so smoothly that I found a brake was necessary. The first couple of brakes I tried were much too flimsy, and I finally settled on the assembly pictured here — a block of aluminum with a convenient semi-circular bore somewhat larger than the axle itself. I adjust the tension by turning a ⅜" bolt through a tapped hole in the steel table until the aluminum block and belt-leather lining inside the bore tightly engage the axle. This is a crucial brake for the assembly, since any imbalance in the telescope is translated into motion of the polar axle without a brake.

Near the top of the 1.188" polar axle I have attached a slewing drive pulley. The pulley is fed by a small aluminum friction wheel attached to the ⅜" shaft of a 400-1 gear box which I bought cheap at a local surplus tool shop. A Black and Decker drill (DC, rechargeable) powers it. I removed the handle of the drill, which held the batteries, and mounted the drill with a U-bolt. This use of the Black & Decker provokes a lot a laughter from my friends and fellow TMs in the Denver Astronomical Society, and I think it is rather funny myself. However, the drill is perfect for this application. The motor is extremely powerful (it cannot be stopped by hand), and provides high torque even at speeds less than one RPM. The chuck, meanwhile, accommodates the ⅜" feed shaft. Thus, at high drill speed, I can slew the telescope quickly from object to object in right ascension, or at low speed merely float an object gently back into the center of the field if it has drifted out.

To another pulley which fits on the top of the polar shaft, I have attached a two-inch pipe flange, and to that a pipe junction. One end of the junction secures the two-inch diameter pipe reducer to accept the counterweight, a cylinder of steel bored out in the middle — yet another junkyard find. A short section of pipe screws into the other end of the junction, and is attached to another flange. This flange is bolted to a steel plate which is in turn bolted to a lazy-susan type bearing. I bought the bearing

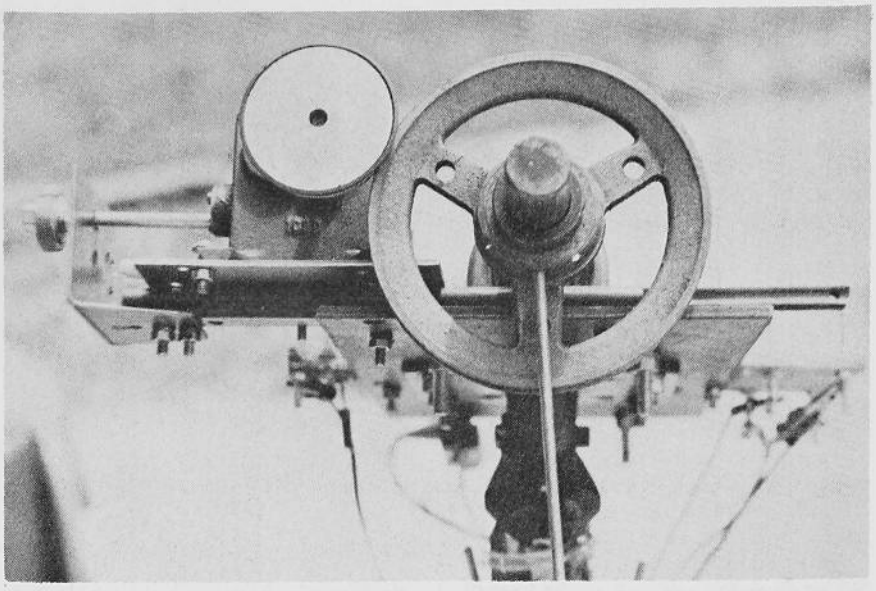
from JerryCo, attached steel plates to each side, and secured both plates through their centers by means of a ½" bolt. Long steel arms are bolted to both the bottom and top plate.

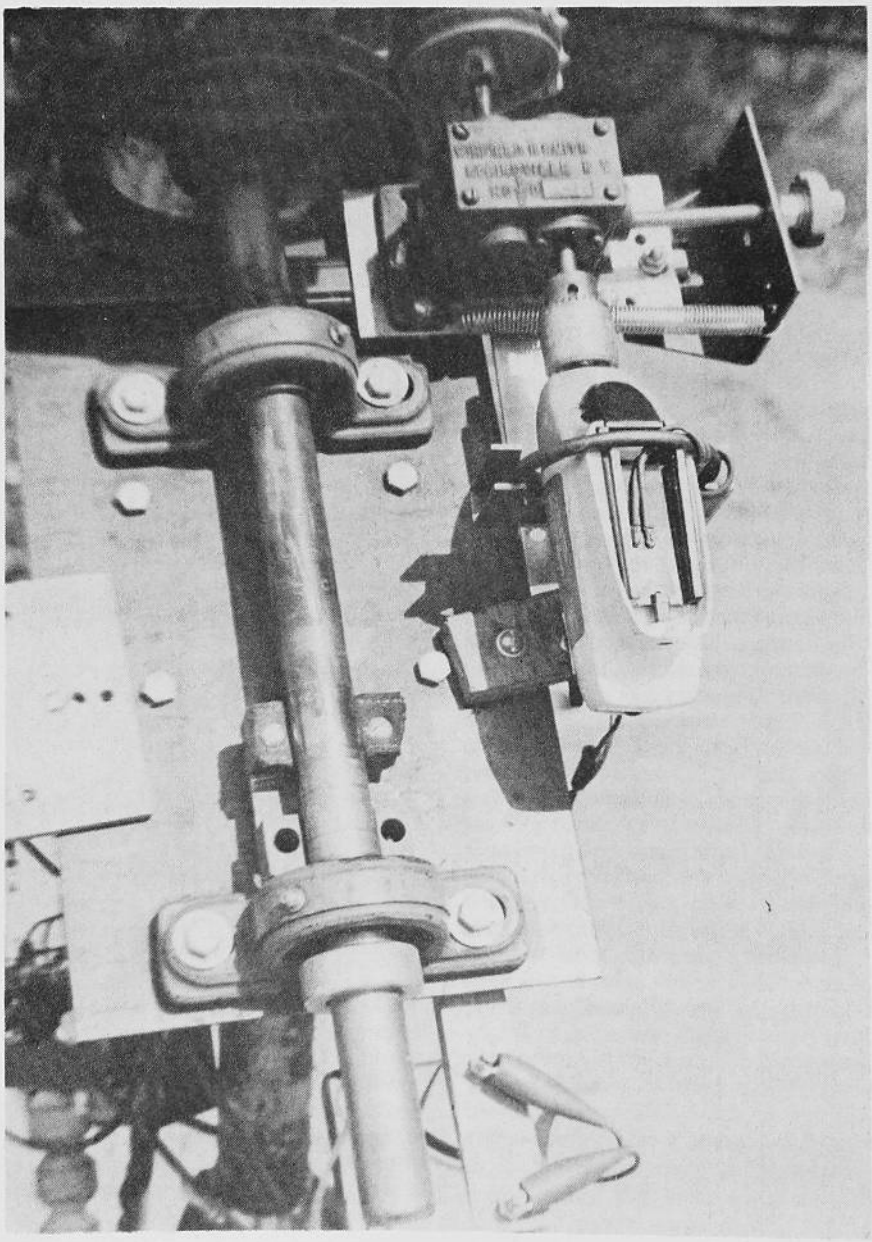
To the end of the rigid bottom arm I attached a motor of the sort used to power a child's toy car — a brute of a motor with plastic gears. The gears, however, must be kind of plastic steel because they are extremely tough. I attached a ¼"-20 bolt to the motor shaft to power the nut attached to the arm of the upper steel plate, and this is the tangent slewing device. A wide variety of speeds is possible with it. However, I must be very careful in transporting this unit. If the ¼" bolt is bent even a little, an awkward motion results, and the star to be centered sine-waves its way back to the center of the field!

This declination slow-motion/slewing arrangement is not as versatile as the right ascension slewing arrangement, however, because the movement of the lazy-susan bearing is restricted by the length of the ¼" bolt which powers the moving arm. The total motion possible is adequate — about 5° either way. Meanwhile, the telescope can be moved in declination a full 360° on the pipe threads of the pipe junction. Clutching can be accomplished by tightening the drive pulley screw. When the screw is tight, the whole assembly can be moved in right ascension by the gear box on the polar axle. When the screw is loose, no motion is transmitted to the telescope, and it may be slewed manually on the pipe threads to any part of the sky, after which the declination slow-motion may be activated.

One of several weak points in my design so far is the cradle assembly which is attached to the top plate of the lazy-susan bearing by means of a flange-pipe-flange arrangement. The cradle is made out of half of a junked streetlight. Plywood semi-circles lock the telescope in the cradle by means of a hooked ⅜" bolt. This cradle is simply too small to hold the telescope as rigidly as I would like, and the rather thin aluminum of the streetlight flexes. Until I can fashion something more rigid out of some new piece of junk waiting in a junkyard somewhere, I'll stick with this cradle because of the convenience of operation. The whole thing can be operated with one hand while I hoist the telescope up almost six feet with the other — a maneuver which I can accomplish in the dark. Without an easy-on, easy-off cradle for the telescope, I probably would not use the telescope as much as I do. The optical tube can be attached to the mount in about a minute.

On a typical evening, I'll carry the tube assembly outside and be ready to observe in three to four minutes. The





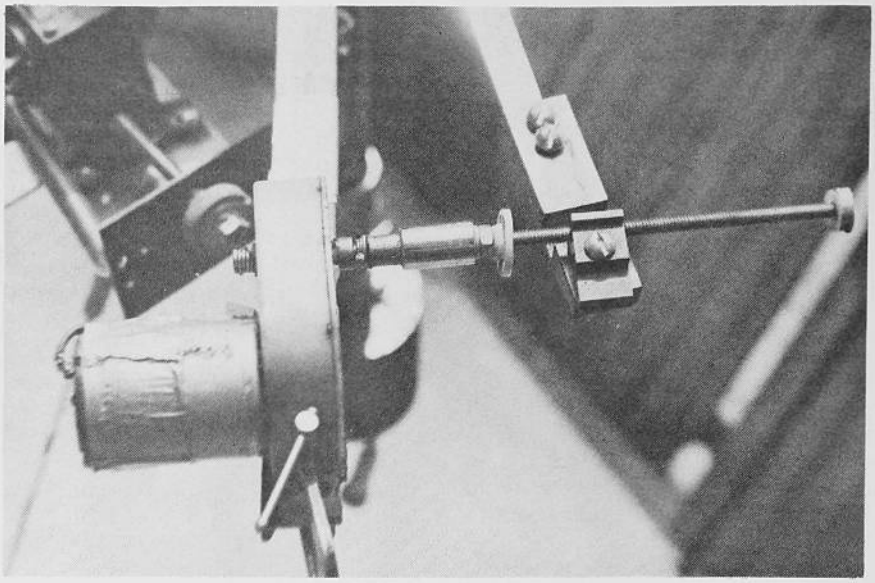
observing I do with the telscope is considerably enhanced by this convenience, as well as by the controls on the "wand." I can slew the object to the cross hairs of my finder, and then focus the 6″ telescope eyepiece electrically. The wand consists of a handful of switches and buttons powered by a surplus 12-volt motorcycle battery which I also bought from JerryCo.

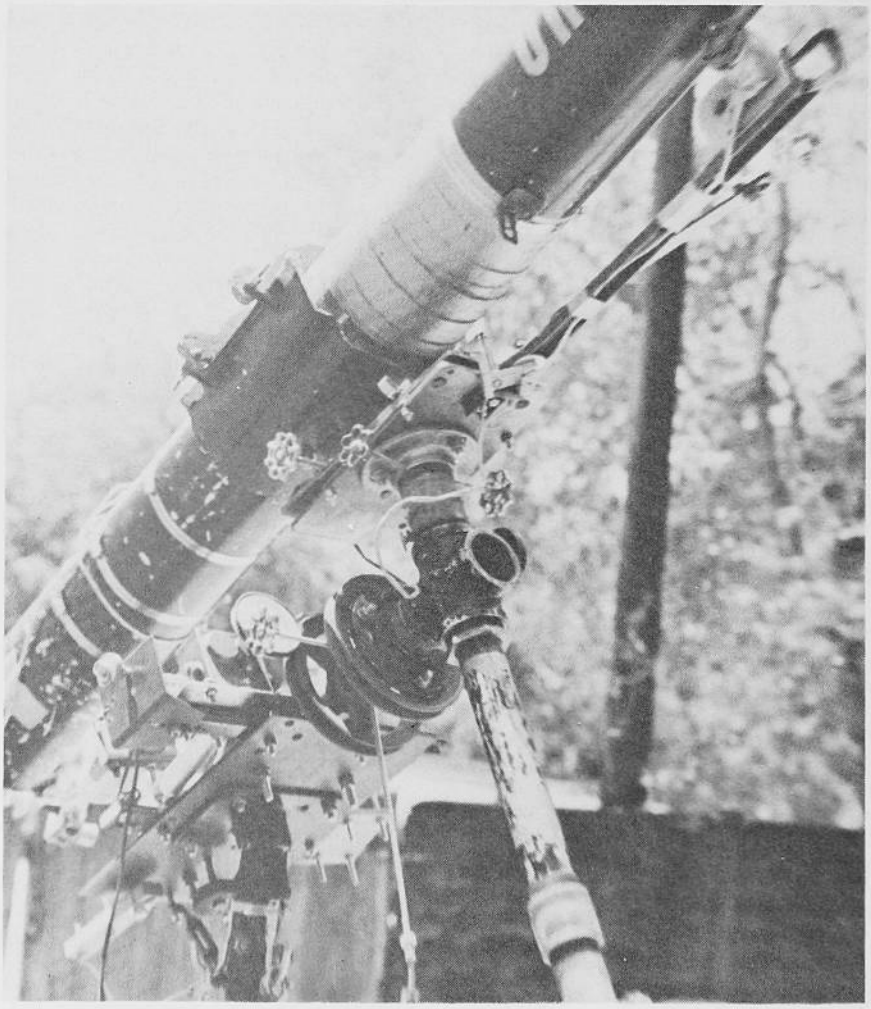
One of the switches is a toggle that controls the focus. This is a low-rpm DC barbeque rotor which turns the pinion gear very slowly with almost no vibration. For major changes in eyepiece focal length, I rack the eyepiece holder in and out by hand via a wheel/clutch mechanism, which is nothing more than a ¼″ shaft tightened or loosened in a ¼″ cylinder attached to the protruding pinion of the focuser.

I must admit that to a great extent my motive in doing so much motorizing of this giant scope has been the simple one of keeping my hands off it. Refractors are notorious for weathervaning, and my poet's refractor seems especially susceptible to the whims of Aeolus. However, in my back yard, which is sheltered on all sides by fences, walls, and trees, I only rarely experience debilitating wind shake, and because most of the necessary movements are motorized, I need not transmit unsettling energy by touch.

What of actual observing? On a large cement platform in my yard, I can observe about half the sky. The northeastern sky, for the most part, is blocked by trees and streetlight glare. However, the southeastern and all the southwestern sky is mine — the moon, the planets, Orion, all of Sagittarius and Scorpius sooner or later swim into my ken. The double-double resolves into splendid points, as do Gamma Leonis and many other doubles. When I attach the huge, hand-machined diagonal I bought at a DAS auction, and insert in it the 63 mm symmetrical eyepiece from the M-70 periscope still carried by some surplus houses, the Great Nebula in Orion glows with more contrast and detail than I can begin to describe. It is a great joy to slew this optical porthole back and forth between the Great Nebula and the magnificent multiples and clusters which form the other naked eye "stars" in the constellation's sword.

The planets are magnificent — I saw more detail on Jupiter in my first glimpse of that planet through the 6″ than I had seen in many years of observing. At our recent Astronomy Day star party, one observer said that the view of Saturn he had through the 6″ was the finest he had ever seen, except through much larger observatory instruments. Needless to say, I am proud of this scope, which breaks down into three or four manageable parts for hauling up to Golden Gate Park where the skies are dark and the lights of Denver are blocked off by an accommodating ridge. Up there, one experiences the sublime. As I slew between gas clouds and star clusters many light-years distant, I am reminded of my favorite lines from Frost:





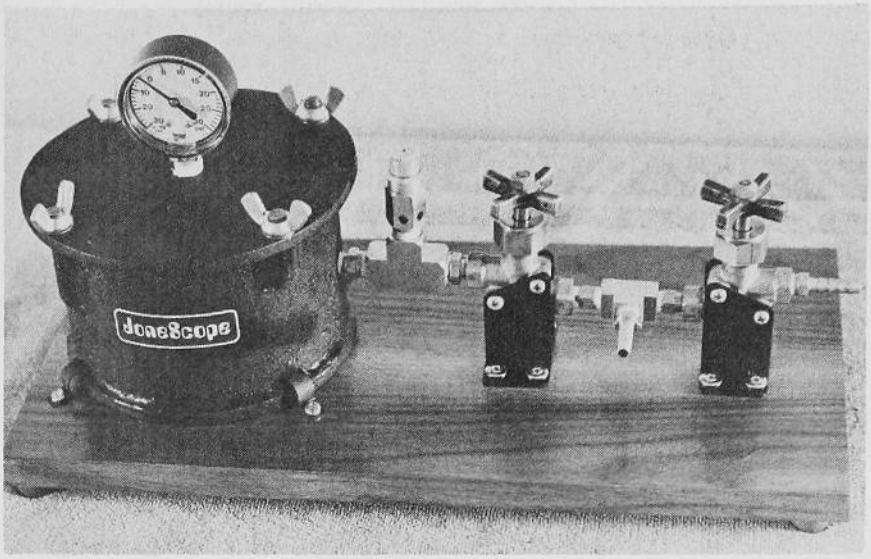
My object in living is to unite
My avocation and my vocation
As my two eyes make one in sight.

Up there, my poetry and my hobby are made one.

William Zaranka
2105 S. Fillmore
Denver, CO 80210

■

A Low Cost Film Hypersensitizing Unit



Intrigued by the recent flood of articles on hypersensitizing common film emulsions with hydrogen gas, I decided to experiment with getting increased performance from the various rolls of film I have. My only problem, which I am sure besets many other astrophotographers, was lack of sufficient funds to purchase a commercially made unit. So I decided to build my own.

All that is required is a chamber of some sort to sensitize the film in, and a way to pump the air out of it and then refill it with the sensitizing gas. The chamber must be capable of maintaining a vacuum of at least 30" Hg and a pressure of at least 30 psi. I decided to exceed these specifications for safety's sake. I looked around for a section of thick walled steel tubing, and eventually found a piece measuring 5.5" OD, having a wall thickness of 0.25", and a length of 3.5". Almost any size tubing will work, depending on the chamber volume desired. I chose the ¼" wall thickness because it was my intention to cut an O-ring groove in the end of the tubing. Since I wanted to use an O-ring with a cross sectional diameter of 0.125", the groove was cut to a width of 0.125" and a depth of approximately 0.090". This groove should be cut before any welding is done to the unit, since some warping of the tubing can occur due to the extreme heat of the welding. Although my chamber ended up slightly out-of-round, it seals with only moderate pressure on the retaining wing nuts.

The next step was to weld a ¼" steel plate to the bottom of the tube and four threaded studs near the top. These studs were ⅜" bolts before I cut the heads off them. I used a grinder to smooth up the welds.

The top was made from another piece of ¼" thick steel plate, faced on the lathe, and drilled to accept the studs welded on the chamber. The top was also drilled and tapped ¼" NPT to accept the gauge, and the chamber was likewise machined for the rest of the "plumbing." The unit was then given a coat of black epoxy paint on the inside (that's what I had on hand) and black wrinkle enamel on the outside, since the wrinkle effect covers a multitude of scratches and dents and leaves the unit with a nice appearance. The addition of a few of my custom labels "tweaked out" the appearance. The entire chamber cost me of $12.50 out of pocket (the cost of the gauge and O-ring). Needle valves, a safety valve, and remaining fittings increased the cost to about $20.00.

I bought forming gas (90% nitrogen and 10% hydrogen) in an "E" size cylinder (about 4" diameter and 30" tall) which contains 20 cu. ft. of gas. Normally a mixture of 92% nitrogen and 8% hydrogen is used, or at least that's what most people seem to be using, but the gas I bought was being used by a local customer and the gas man was able to fill my order immediately. It cost $50 from my local oxygen supply firm. I had to buy the cylinder ($40 of the $50) since they would not rent cylinders of this size. In my case this is acceptable since this amount of gas will most likely last me many years, and purchasing will end up being cheaper than renting. I can have the cylinder refilled for about $10.

Adding a borrowed vacuum pump and a regulator for the gas cylinder completed the unit. The safety valve was adjusted to start leaking at about 30 psi, so I consider this unit safe.

I cannot stress enough the need for safety when dealing with high pressure cylinders of gas. True, you will only have 15-20 psi in the chamber, but the gas cylinder can have pressures in the range of 2000 psi. The use of a regulator is highly recommended if not mandatory. If you borrow a regulator from another cylinder as I did, make sure you don't get one from an oxygen cylinder, since you can never reuse it for oxygen. Hydrogen impregnates the metal of the regulator and could cause an explosion on contact with pure oxygen.

At a total cost of about $75.00, I now have a film sensitizing unit that is quite simple to operate. The cylinder of gas is good for about 200 fills of the chamber. Therefore I can sensitize 400 36-exposure rolls of my favorite 35mm film (since the volume of my chamber is sufficient to hold two developing reels loaded with film), or 200 rolls of 120 film, cut film, glass plates, or any other form of film I can cram inside. The number of fills will vary depending on the chamber pressure.

When I want to gas only one reel of 35mm film (as is most generally the case), I fill the chamber halfway with marbles to displace unneeded volume.

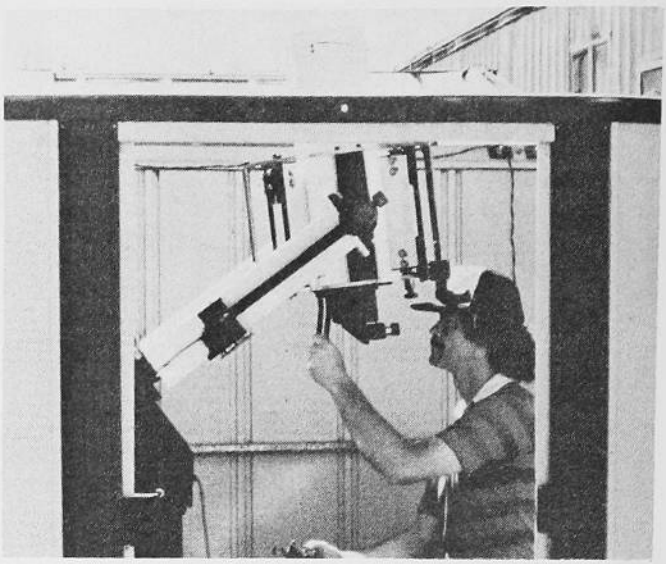
This unit was designed to operate at room temperature since I have a lot of 103a film, and thermal fogging occurs at higher temperatures. But for other films, and especially 2415, higher temperatures are desired. A heating element (similar to the heating tape available to wrap around water pipes to keep them from freezing) is connected to a variable power source and is wrapped around the chamber to increase the temperature, thereby shortening sensitizing time. (Every 7 to 10° C rise in temperature cuts the soaking time in half.) A quality thermometer should also be added to monitor the whole works.

My unit operates just like the commercial units, but at a cost of only about 20 cents per 36-exposure roll of 35mm film. When I have the gas cylinder refilled, the cost of sensitizing will be only about 5 cents per roll. Now that's what I call reasonable!

Donn E. Jones
PO Box 867
Delaware, OH 43015

■

Dual 6" f/15 Cassegrains

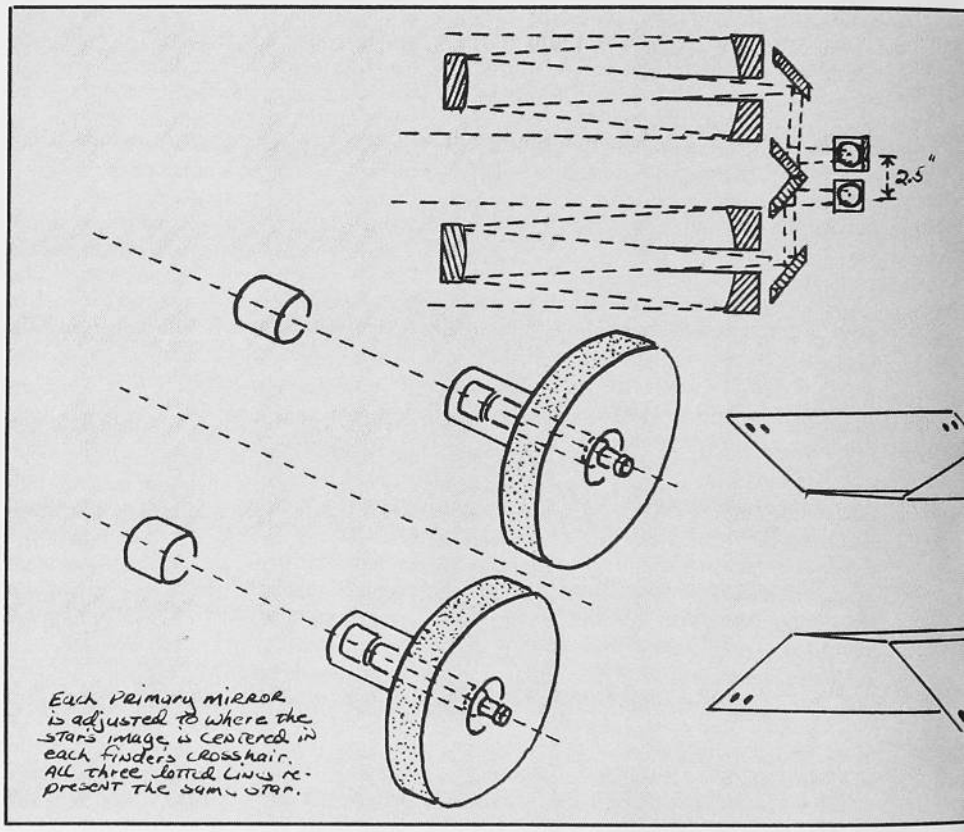


The design and construction of my 6" f/15 Cassegrain binocular took a little over two years from start to finish. I wanted an optical system that would afford me the opportunity to use both eyes at the same time, but the cost of large commercial binoculars ruled out my purchasing them. So I decided to design and build my own using mirrors instead of the more expensive objective lenses.

For an optical system of this type, I felt that twin Cassegrain systems would be the simplest to design and construct. The biggest drawback is that this optical system requires five reflections on each side in order to transfer the image back down to the eye. For the optics, I ordered a pair of Coulter Cassegrain mirrors and hyperbolic secondaries because of their low cost and proper focal lengths, especially the back focus of approximately ten inches. The back focus was critical — in order to accommodate a larger back focus, I would have had to increase the separation between the optical tube assemblies. This would, in turn, have made a larger fork necessary to hold the optics. I used three first-surface mirrors at the rear of each Cassegrain assembly to transfer the reflected image to eyepieces taken from a 7x40 Zoom Bushnell binocular.

To make this type of system successful, I had to come up with a mechnical design that would enable me to rotate the whole binocular around a common axis. At first, I drew up many different ideas that I felt would work, but many seemed too complicated to be practical. I finally decided on a double steel ring system. Motor pulleys, eight altogether, carry the optical parts inside the steel rings.

Both steel rings are supported by four aluminum brackets approximately 12" long and 3" wide. They are secured with two ⅜"-16 Allen bolts on each side of either ring. Four ½" steel shafts approximately 12" long are also secured to each side of either steel ring.

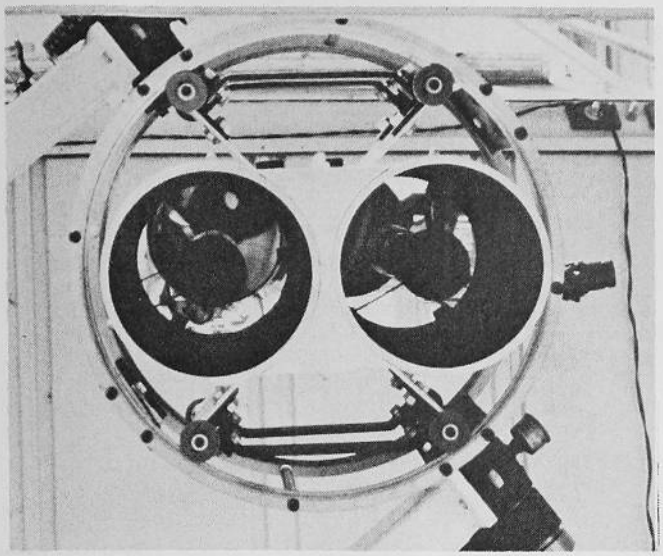


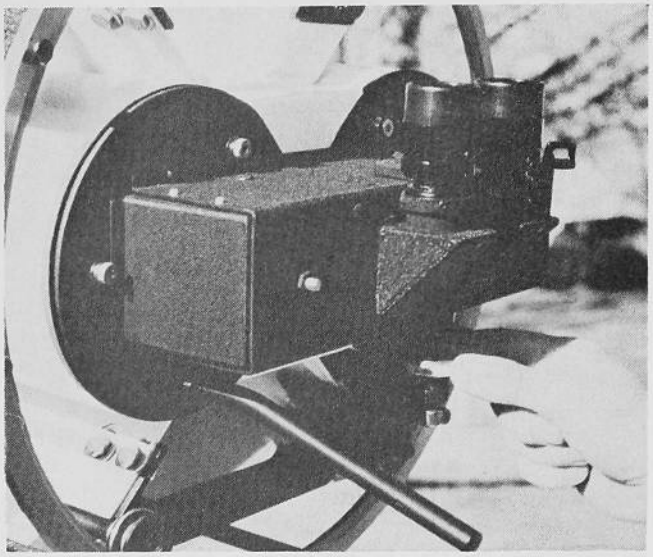
After completing the rotating ring system, the eight motor pulleys were mounted on the X bracket frame that carries the two telescopes. Eccentric slots allow adjustment and centering of the optical tubes in the ring. The support brackets came from an old ice slush machine, and because of their right angle mounting flanges, they were just right for the X bracket frame. The ½" shafts were welded to the brackets.

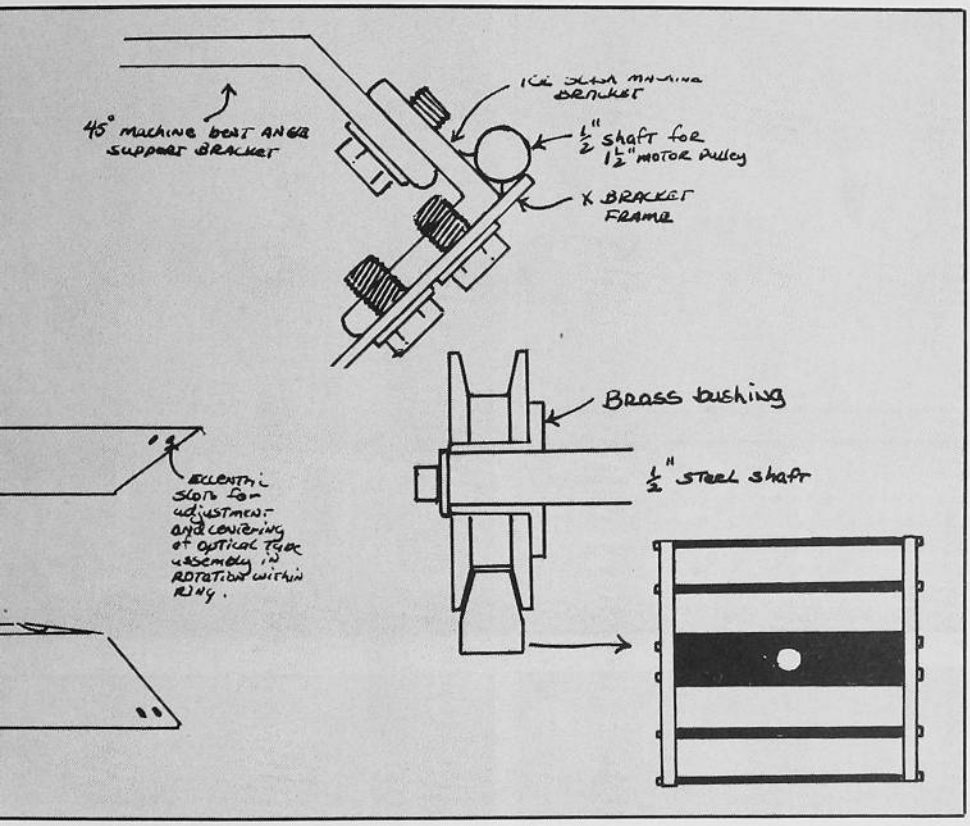
I drilled and tapped the ends of the ½" shafts to accept a ¼"-20 Allen screw holding a 9/16" washer. These keep the 1.5" diameter motor pulleys from coming off the ½" shaft. All eight shaft ends have a pulley.

The X bracket frame is made out of aluminum and bent at a 45 degree angle. Both X brackets are mounted on either side of the middle section of the optical tube assemblies, and both are secured by five ¼" bolts and nuts.

The completed assembly with all eight pulleys rotates very easily within the dual steel ring unit. It took several hours to get the optical tube assembly centered perfectly within this unit, but I simply







used trial and error until the optical tube assembly rotated smoothly and without any hangups.

With this working properly, I felt that I had achieved one of my major goals. It permits the observer a comfortable head and eye position. Without the rotating assembly, I would be at the mercy of the Earth's rotation when observing.

Calibration of the 6" f/15 systems was perhaps the most difficult part of the entire project, yet probably the most rewarding. I knew I was going to have problems in this area, but I proceeded in hope that I could somehow figure out how to lock all ten mirrors into perfect alignment.

The first step was to mount the two 6" f/4 primaries into two Meade mirror mounts that I modified by epoxying a baffle tube into the two-mirror-cell Cassegrain opening. After the mirrors were secured in the cells, I placed them in the tubes. I then installed the secondary holders and began to prepare for the initial step in calibration of the dual system. Having placed the optical tube assemblies in the rotating mount and into the fork, I put small finder telescopes (wrapped with masking tape so they fit) into each baffle tube assembly. Only their eyepieces protruded from the mirror support plate.

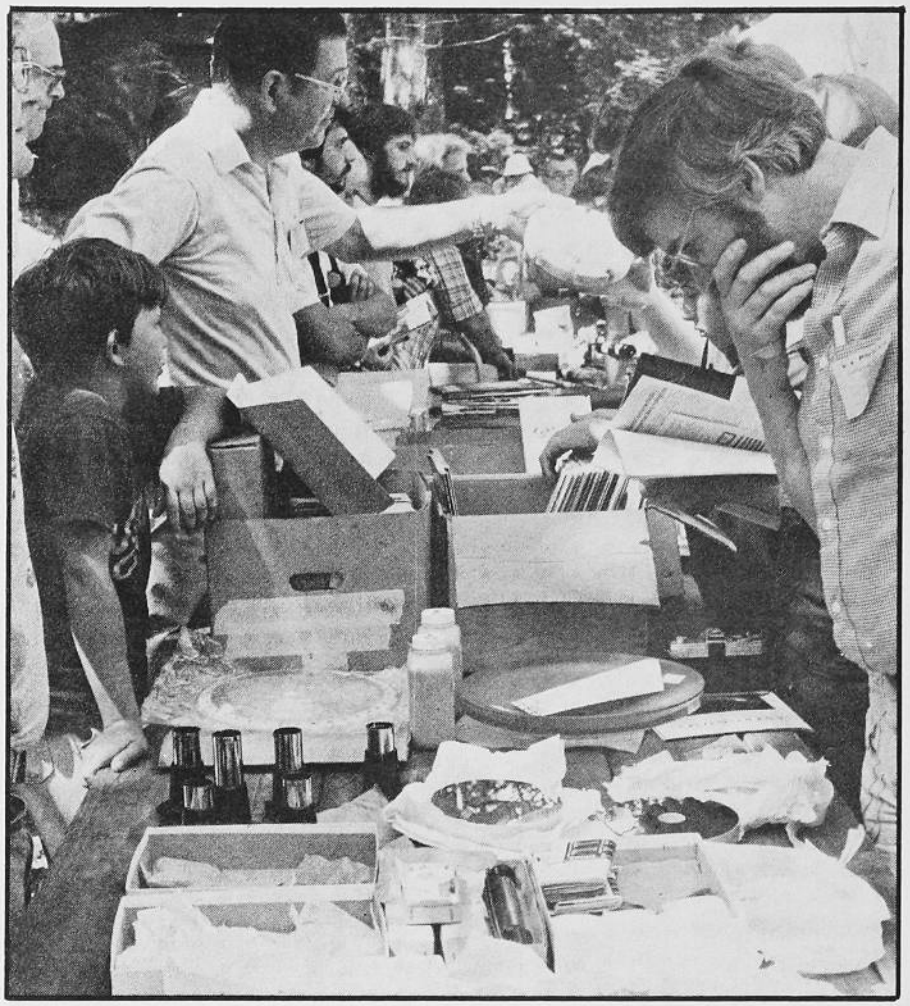
After aligning the polar axis of the telescope to true north, I located Sirius and used it as my calibration star to align the primaries so that when the telescopes are rotated in the rings, the test star remains centered. Then I put the secondaries in the tubes and centered them making sure that each was at the appropriate distance (16.9") from its primary.

The final adjustments are made with the two side-mounted first-surface mirrors. They are mounted on the three-point suspension system with small springs that provide the tension. Adjusting them centers the image of a test star in the center of each eyepiece.

Using binocular eyepieces in conjunction with the 6" f/15s, the magnification of the eyepieces ranges from 105x to 315x using the zoom. In the Bushnell binoculars, the magnification was 7x to 21x. All adjustments are made at 315x. For comet hunting, I can use a pair of 40mm eyepieces for a magnification of 57x. I'm happy to say that the binocular affords me a unique opportunity to view the skies. The eyes and brain generate a remarkable stereo effect which is particularly stunning on the Moon and planets.

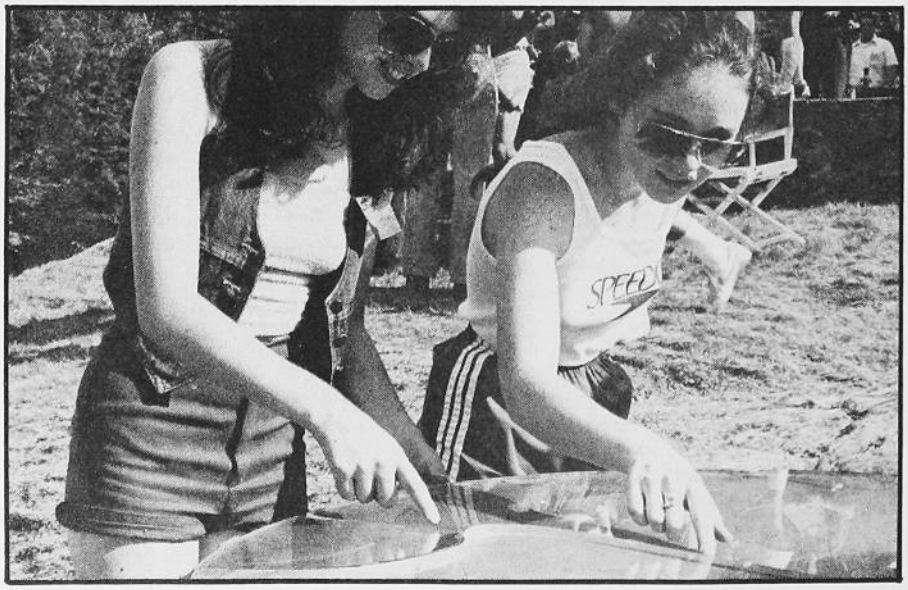
I made the equatorial fork from scratch — from the fork to the pier itself. One thing I'm proud of is the power for the lights and motor on the fork: I used four brass rings with carbon brushes. The weight of the entire telescope and mount is about 500 pounds. By the way, Kenneth Keyser took the photos for me.

Norman Butler
President
Manhattan Astronomical Society
Redbud Estates #26
Manhattan, KS 66502
■

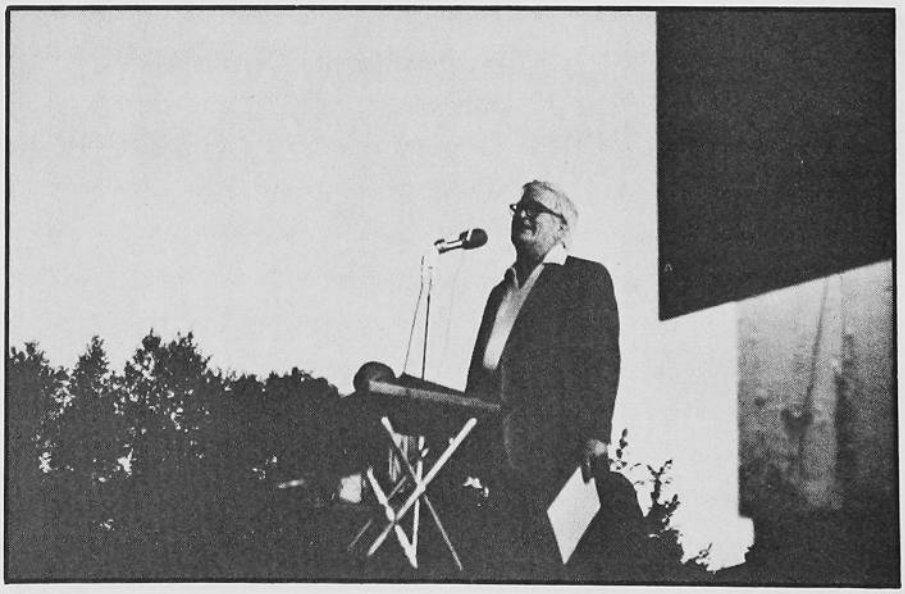


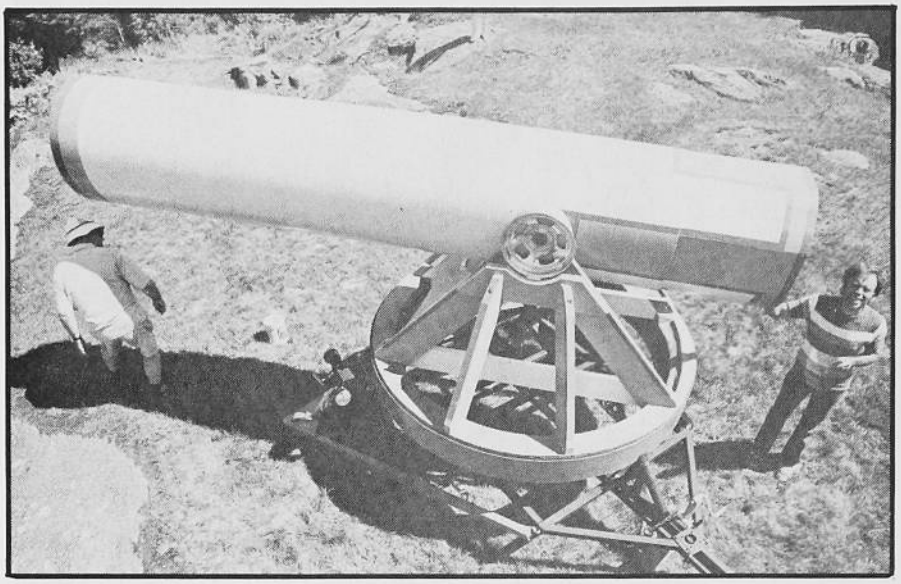
STELLA

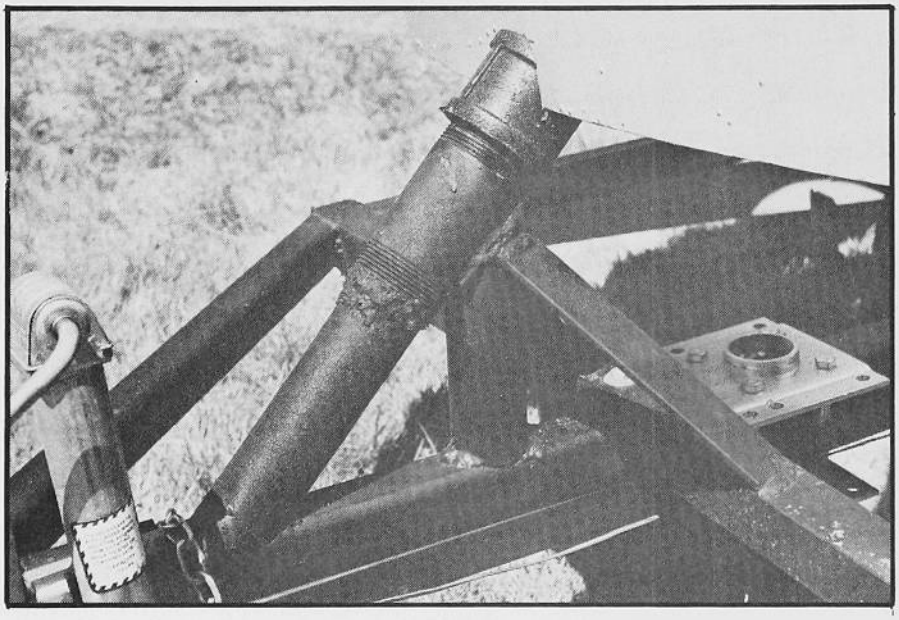
This year's Stellafane featured fine clear nights (right), a 22" Dobsonian on the Hill, an active swap table (above) that ran all day Saturday, a somewhat mysterious 275 pound, 48" diameter Clarke autocollimating flat brought by the Skyscrapers Club. During the day, it cracked into three pieces under the intense heat of the Sun. Good weather brough excellent attendance (800 by Friday evening, about 1500 present on Saturday). Walter Scott Houston delivered the Stellafane Shadowgram Saturday night.

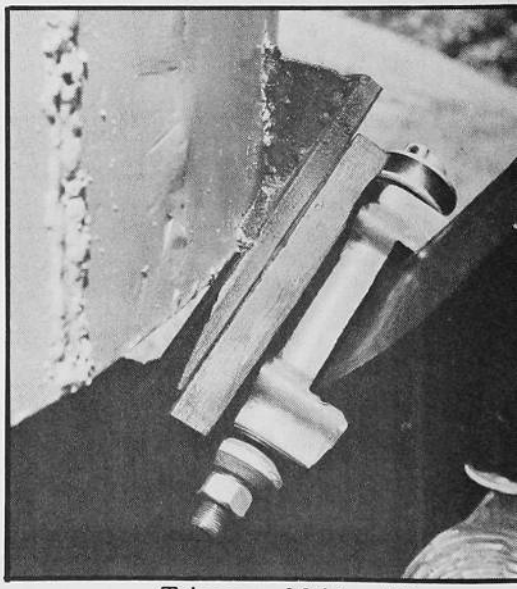


FANE 1981



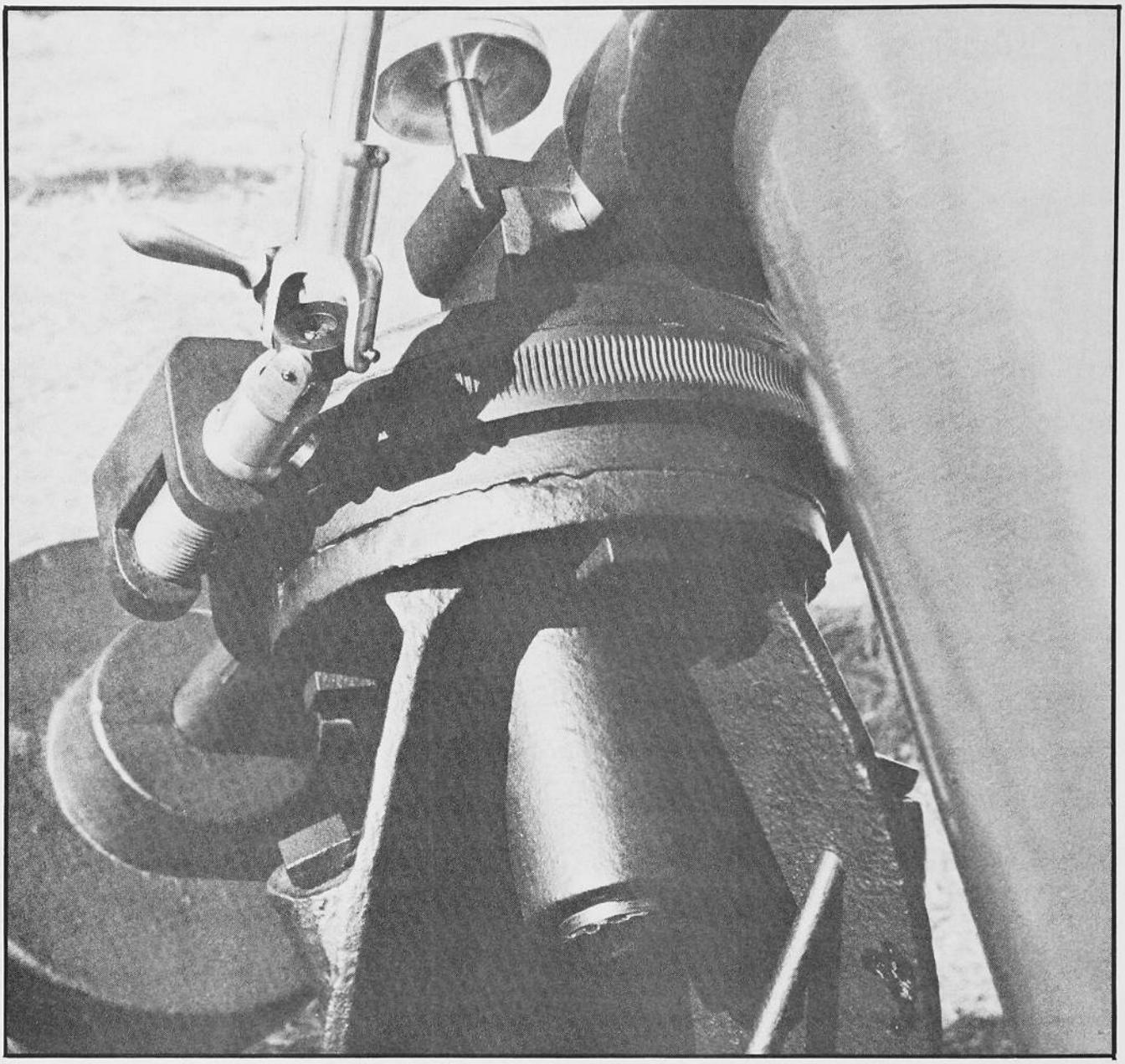


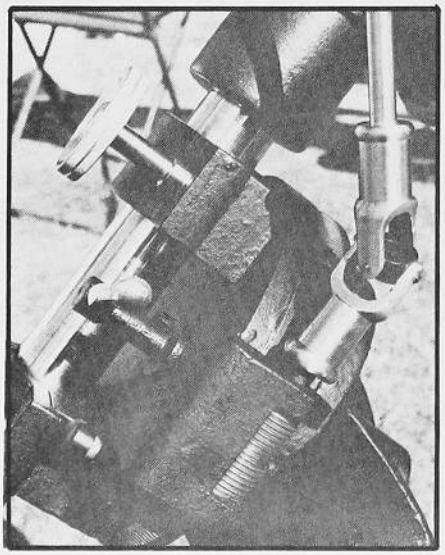


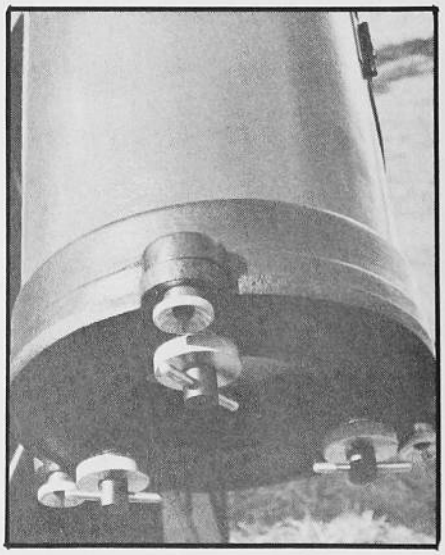


It was the biggest telescope ever shown at Stellafane — a 22" f/7.3 Dobsonian built by Steve Dodson of North Bay, Ontario. Gerard Pardeilhan and John Dobson of the San Francisco Sidewalk Astronomers made the mirror for one of their telescopes, and several years ago sold it to Steve. He designed and built a trailer-mounted massive alt-azimuth table with an equatorial third motion rather like a Poncet platform — but not quite (should it be called a Dodson(ian) telescope?). Note the huge base ring for stability, the RA grinding-wheel arbor rollers, and the south end of the polar axis — a large pipe fitting. Steve will descibe this instrument in detail in an upcoming TM.

1930

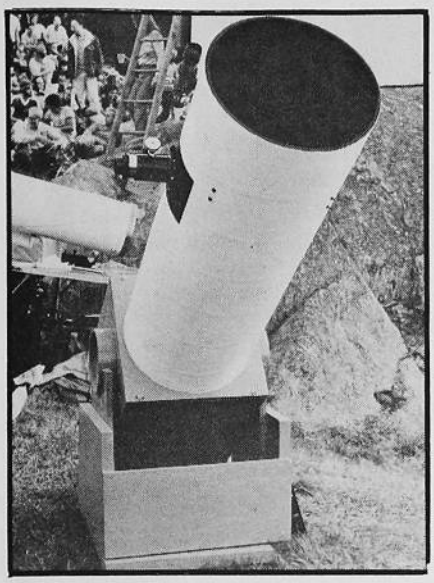


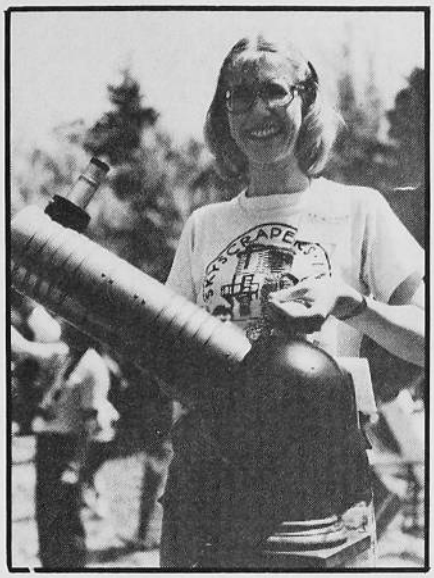




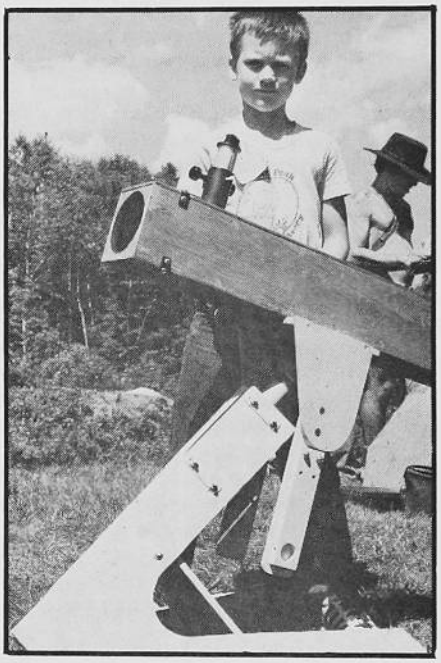
They just don't make 'em they used to. Rick Schmidt and Ken Launie brought a beautifully restored 1880s or 1890s 5.5" f/8 reflector that puts today's commercial telescopes to shame with its stability and elegance of design. According to family rumor, the telescope was built in Germany, and purchased by Harry Moore, Rick's great grandfather, a traveling Shakepearian actor. Grandpa Moore set it up in Missouri (see comtemporary photograph) where he owned a rock quarry. Particularly impressive is the equatorial head and pier, with a simple device to engage and disengage the gear for slewing and tracking. The pier and base are two parts joined with lead, steadied by ½" stabilizing bars. Does anyone have information about the makers of this telescope?

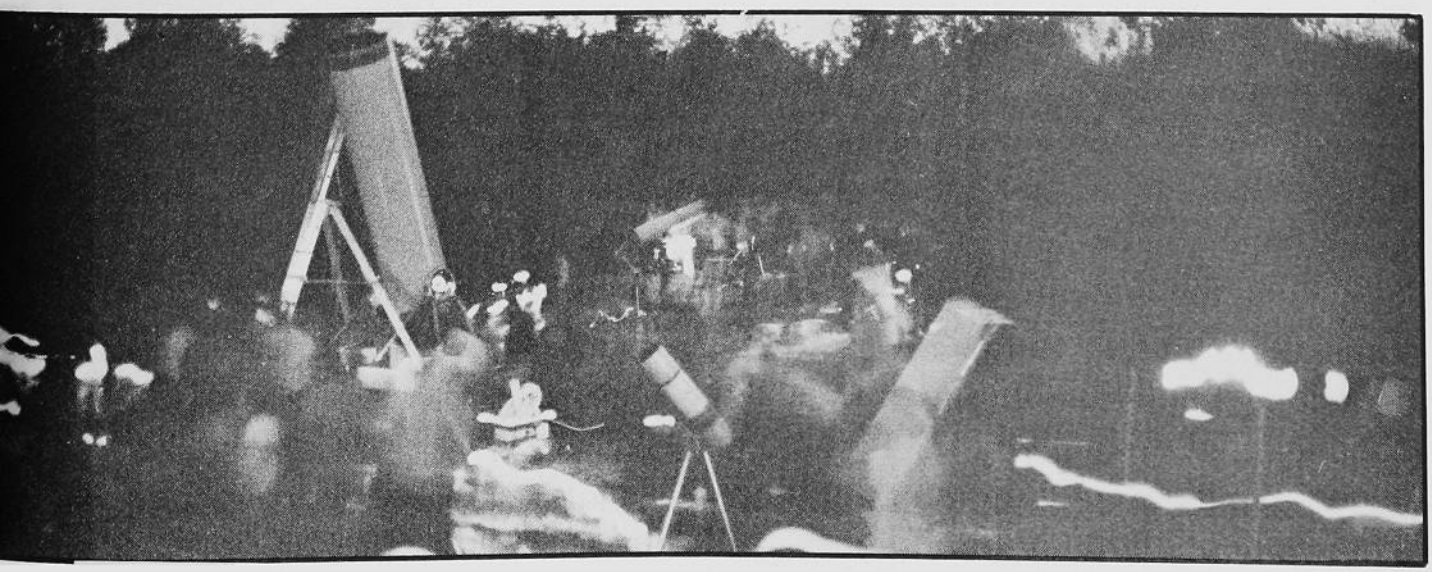
This page, left: Mike Simmons beside his 4.5" f/8 fluorite achromat. Opposite page, lower left: Roland Christen's 5" apochromatic refractor gave utterly magnificent images. It will be written up in a future issue of S&T. Upper left: Walt Hamler's 12" Dobsonian has a detachable front end for easy transport. Top: Denise Turco built this 4" f/6 bowling ball telescope with a 16 lb. ball and two big coffee cans. It rotates on a base made from an old hatrack. Upper right: Neil Hunt of Deep River, Ontario stands behind his 10" f/5.5 Newtonian mounted on a tree-trunk pier. Lower right: Alan Beaman, age almost 9, posed behind his 4" f/7 on an inverted fork mount. Dad helped a little bit. Alan said he'd seen M-27,13,11,57, Jupiter, Saturn, and R Leonis so far.





STELLAFANE





Making an Improved "Simple" Focuser

Here are some additional notes on "improvements" for the Dobsonian that I've found while working on mine:

The top of the tube box is a practical place to mount a star chart. Attach it any way you want: thumbtacks, clips, masking tape — you name it.

For illumination, a handy-dandy light is easy and inexpensive. Here's a few I've tried. 1) G.E. clear red 25-watt 120 volt decorative "Party Bulb" $1.25; 2) Plastic trouble light cage housing from any auto parts store $.89; 3) Simple electrical light socket from the hardware store. With enough cord it should be about $2.00.

Now, here's another, an improved "simple" focuser for the Dobsonian or any other low-cost Newtonian where you don't want to pay $25 just to hold an eyepiece steady.

Materials required are minimal, just two 3″ x 6″ clear soft white pine blocks, two #110 x 2″ FH or RH stove bolts with nuts and washers to fit, and two extra washers if you use RH. For the eyepiece tube, purchase a piece of chrome coated brass sink drain tube. About $2.

Here's how to go about making the holes in the wood:

1. Fasten the blocks together with 1″ nails, two from each side, in opposite corners. Do not separate them until all holes are drilled.

2. With a knife or coping saw mark a "V" across one end of the blocks as register marks. The blocks must stay in this position in relation to each other from this point on.

3. Mark a center line on the long dimension of both blocks and mark a center point on one. Make two more marks for bolt holes on centers 1⅛″ each direction from the center mark.

4. Bore hole for focusing tube (at center point) through both blocks. I used an expandable bit with a brace and made several trial holes in scrap until I got a very snug fit with the chromed brass tube. Sand the holes lightly to remove roughness but not enough to make them sloppy.

5. Insert the tube into both blocks.

6. Drill the first bolt hole with a drill slightly smaller than body diameter.

7. Now decide which block is going to be inside the tube and mark it accordingly.

8. If you use FH bolts, countersink the inside block bolt hole. If you use RH, recess the hole to allow for head height plus washer and big enough for washer diameter.

9. Insert the first bolt through both pieces. It should turn up snug.

10. Drill and countersink (or recess) the second hole.

11. Now take it all apart and you will have two pieces — inside and outside, registered into position, with three sets of holes which will be in-line upon assembly.

Next, shape the blocks:

1. Lay the inside block's inside side lengthwise in the tube. Note the distance from tube to centerline (the depth of the chord) and make a line along both sides of the block this depth from edges which were contacting the tube. You may wish to draw a smooth curve on each end from the side line thru the center line point and down the other side line.

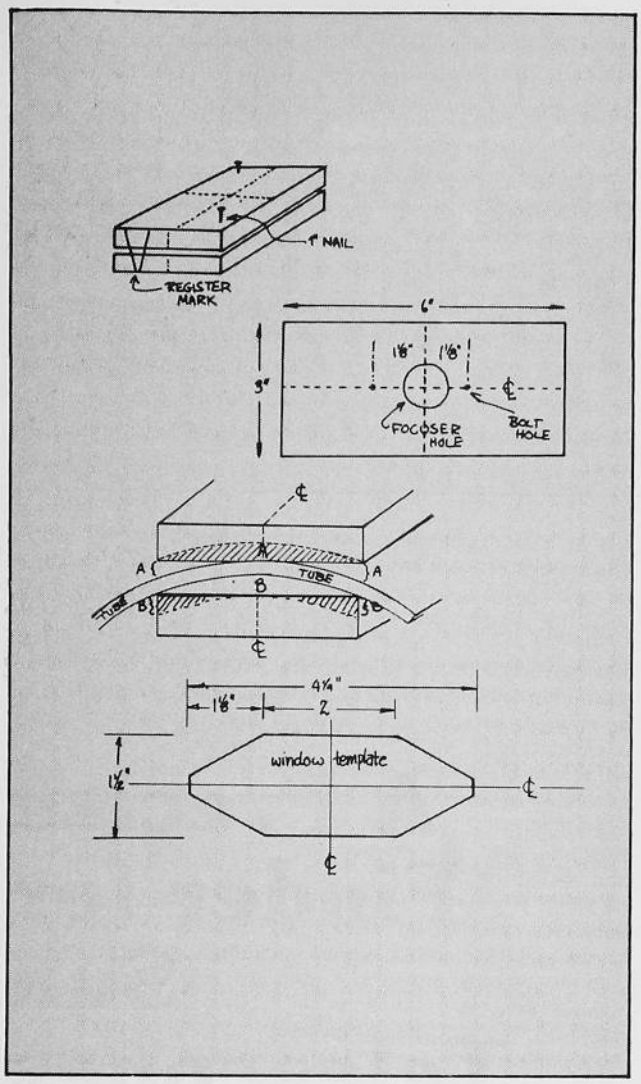
2. The outside piece is done similarly. Lay its inside lengthwise on the outside of the tube with centerline in contact. Note the height of the block's edges above the tube. Mark this distance on both ends of the block up the centerline from its point of contact. Draw a smooth curve connecting edges and point.

3. Remove wood from inside side of inside piece to make a convex surface. This is done with a sharp knife, wood rasp, surform, etc. — whatever you have. Rough it out as close as possible. For the outside piece (concave surface), use a sharp wood chisel or very sharp knife.

4. For a smooth surface you have two choices:

A. Lay medium-grit sandpaper on tube surface and work the piece gently lengthwise until it fits.

B. Lay carbon paper on the tube, carbon side up. Gently rub the block on it. The carbon will show the high spots — sand



them down and repeat as necessary.

5. When the surfaces are true to the curve of the tube, you're done. They don't have to be smooth — they must fit though.

Next is the hole in the tube:

1. Locate center of the window in the tube as for any Newtonian.

2. Make a template out of heavy paper (such as file folders or stencil paper) as shown in the drawing.

3. Mark the axial line down the tube through the hole center. Lay template centerline on axial line and mark the hole on the tube. Be sure template is centered over the center point of the hole.

4. Cut out the hole. Trim any burrs. Varnish or paint the raw edges.

This focuser thing is quick and easy to make. It provides a stable support the focuser tube, means you put only one hole in the tube which is never again disturbed and it allows adjustment of plus or minus ⅞" axially and ⅛" radially. The adjustment is easy (just loosen the nuts and slide whole unit to new position), it doesn't depend on the paper tube for mechanical strength.

I see no reason why this could not serve perfectly well as the mounting base for a rack & pinion focuser, too. The blocks might have to be wider and the outside side of the outside block shaped a little.

Wally Pursell
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Baton Rouge, LA 70815

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A Multi-Eyed Telescope

At the Riverside Telescope Maker's Conference swap meet this year, I purchased a 36" focus f/8 surplus Telephoto lens for $50. The lens was made by Eastman Kodak. I purchased this lens with the intention of using it as an RFT with a large Konig or Erfle eyepiece — or even doing photography with it.

Then this idea occurred to me. Since it used 9"x18" film, the lens should have a wide flat field, so why not put several SLR cameras or eyepiece holders at the focal plane at once? Each could move about independently of the others. You could have several eyepieces looking at slightly adjacent targets in the same constellation at once, or photographing adjacent targets with different types of film and exposures.

I got the lens home, removed the defective shutter, cleaned the lens, and put it back together with the iris in.

I built the prototype telescope out of ⅝" particle board, rather than plywood, because that's what was immediately available. The movable plate is held by four 5/16"x18" threaded rods. The particle board introduced some flexture at the eyepiece end, so I rebuilt the eyepiece end using 1.5" thick plywood (two ¾" pieces glued together). This solved the flexture problem nicely.

The holes in the eyepiece end plates are 8" in diameter allowing several eyepieces and/or cameras at once to be at the focal plane. Commercial focusers take up a lot of space and can't get very close to each other, so I put the eyepiece tubes in narrow plywood boards allowing the eyepieces to get closer to each other.

The lens itself is of fairly good quality. It suffers from blue chromatic aberration wide open but improves as the aperture is stopped down. It is capable of resolving Epsilon Lyrae into four stars with a 6mm orthoscopic eyepiece, on-axis, wide open.

Off-axis definition is very good. Out near the very edge of the field, Gamma Leonis just barely doesn't resolve. Then if I fully stop down the iris, the star resolves very nicely (magnitudes 2.5 and 3.5: 4.4 seconds of arc). I have concluded that the idea of several eyepieces or cameras at the focal plane is feasible.

The rig weighs about 35-40 pounds and I mount it on my Tele-Drive mount. This mount holds the load very well and shake down time from vibrations is only 3 seconds.

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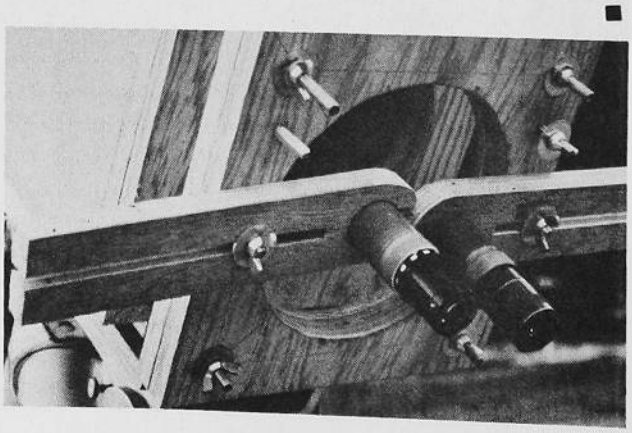

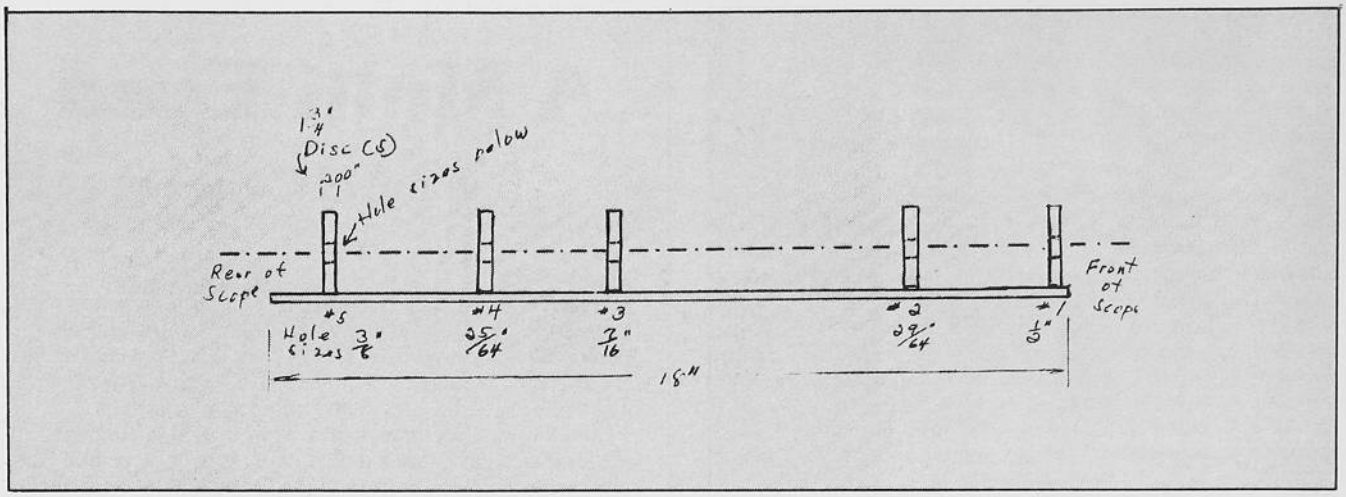

A Precise Finder for Sun Telescopes

It has always intrigued me how the ancient astronomers made such complex and accurate observations. They had to be made without the optical aids we have today, since they did not have lenses or mirrors thousands of years ago. The only thing that came to mind was some use of shadows. The pinhole camera demonstrates very simply the effectiveness of a single hole.

So I started out by turning several 1.75" discs drilled with holes. At this point it became quite obvious this would make a superb finder for a sun telescope. I found that by arranging the "hole" sizes according to the diagram, numbers 1 and 2 function as a coarse finder to put the scope in the general direction with numbers 3, 4 and 5 for the fine tuning.

When the narrow band of light shown on the illustration surrounds the opening in #5 the sun will be precisely in the center of the field of view. It's so fast and easy there is no temptation to squint up the side of the scope. The light band is quickly centered because the human eye is sensitive to small differences in its width.

Paul Zurakowski of the Telescope Makers Workshop in Oakland was enthusiastic about it and Don Warren who heads the Astronomy Department at City College of San Francisco plans to put one on the school C-14 so the students will be able to safely and quickly zero in on the sun.

I wonder if this type of successive aperture was used for some of the observations made long ago. My friends tell me I may have set astronomy back 5,000 years!

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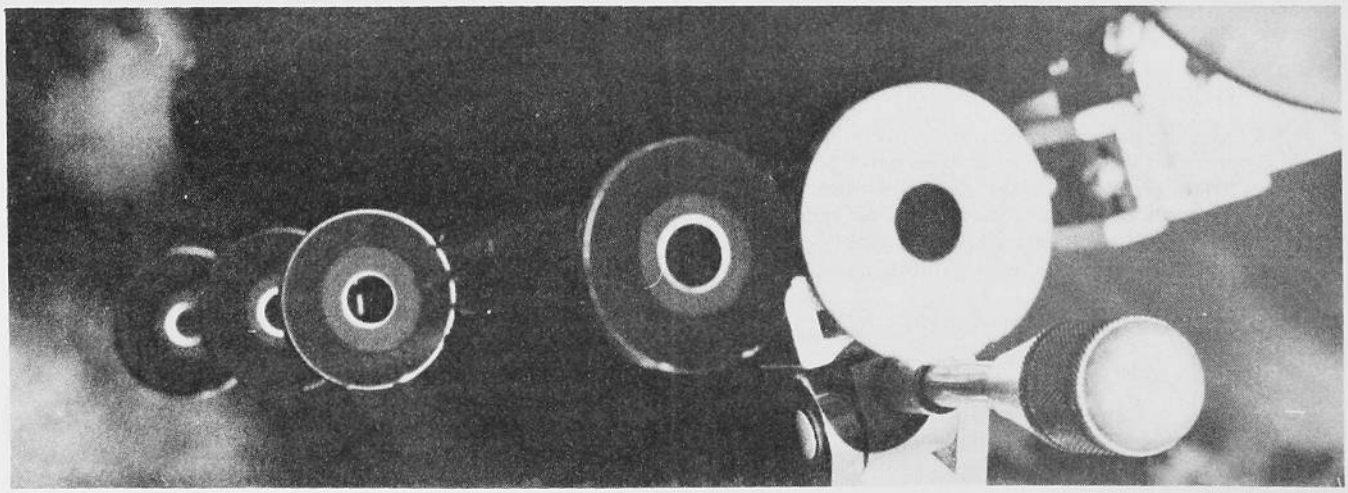

Recently, several members of our club purchased Coulter CT-100 telescopes for finders, telephoto attachments, and for use while backpacking. I intend to carry mine in a flight bag on deployments with a Naval Air Reserve squadron. (I fly an E2B Hawkeye aircraft which has limited space.)

The telescopes are 4¼" F3.5 Newtonians and come supplied with a 27mm eyepiece yielding a magnification of 14X. Shortly after the telescopes arrived, everyone noticed a darkened area in the center of the field of view. A call to Coulter indicated that this was normal and associated with the eyepiece. Also, use of their higher quality 30X and 60X eyepieces would eliminate this problem. Indeed, the problem disappeared when higher power eyepieces were tried. I might add here that everyone is more than satisfied with the instruments and we feel that we received more value than the low price would indicate.

However, the darkened area is not due solely to the eyepiece, but also to the basic design of the Newtonian telescope. If you ask most astronomers about the exit pupil of a telescope, you will usually hear "It is the image of the objective formed by the eyepiece and has a diameter equal to the diameter of the objective divided by the magnification of the telescope." This is true but not only is an image of the objective formed, but there is also a image of the secondary mirror blockage of the objective.

For the CT-100, at 14X, the image of the objective mirror is approximately 7.7mm diameter and the image of the secondary mirror blockage is about 2.64mm. It is easy to see why an observer with a daytime apdapted pupil would experience a darkening when the eye is centered on the optical axis. If the observer's eye pupil were larger than 7.7mm there would not be any darkening effect.

The darkening effect is not present with 30X and 60X eyepieces becasue the exit pupil is reduced to 3.6mm and 1.8mm respectively. If you dark adapt for several hours to enlarge your eye pupil to 7mm, the central dark area is reduced for the 14X eyepiece. Hence, a central darkening is indicative of using a magnification that is too low for the pupil of your eye.

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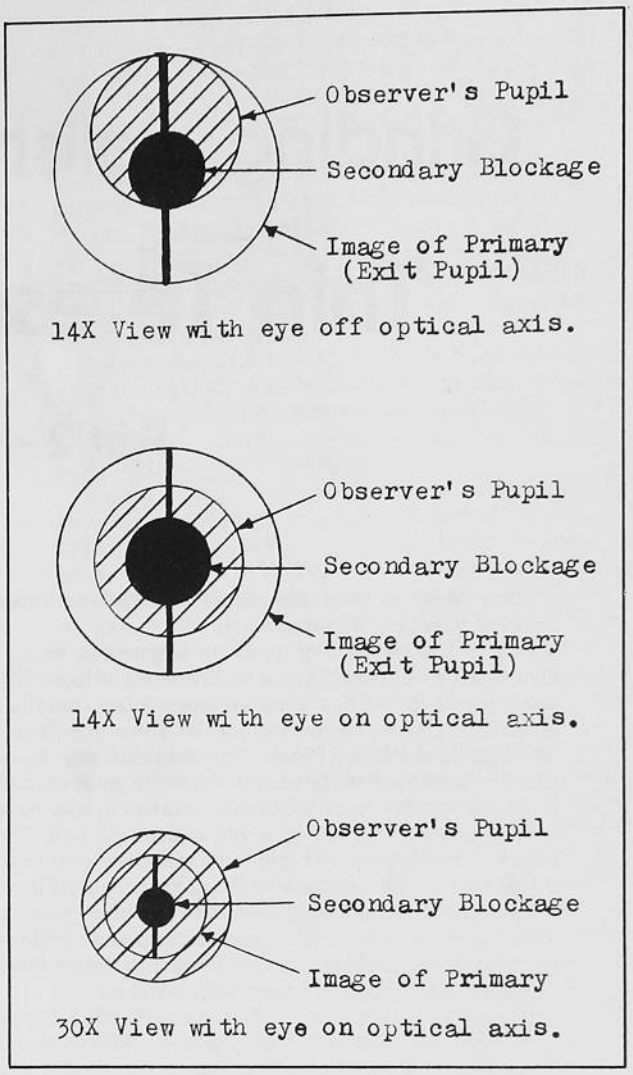

The RFT Central Spot

Grinding, Polishing and Figuring Thin Telescope Mirrors

Part 2 – Polishing

I am going to start with some additions to topics covered in part 1, on grinding mirrors.

First a few cautionary notes on segmented tools. I should have mentioned that a small amount of Ivory dish soap added to the fine abrasive gives you a smoother action if you have a segmented grinder. I have even heard of tile grinders sticking like a solid glass tool if soap is not used. In working the mirror with the final abrasives, that is, those smaller than 9 micron, scratching can be a serious problem especially with a segmented tool. The edges of the tile seem to dig into the glass. If you run into this problem, there are several things you can try. Go on to grinding with your final abrasive right after grinding with the abrasive before — just clean up and continue working. If the problem occurred because the tool was warping when it sat for a time, this will help.

Preventing scratches: Micro Grit® abrasive is available mixed with talcum, which helps prevent scratching. It is signified with a T after the micron size number, for example 5T, for 5 micron with talcum. If you are having scratch problems in 3 micron, try finishing the mirror in 5 micron. Don't finish with anything coarser than 6 micron or 305 emery. You might also try using the abrasive in a thicker slurry, like cream, or adding more soap, or both. A last resort (and one that I have never tried, but I suspect it would be effective) is to bevel all the tile edges on your grinder. If nothing works and the scratches are not too numerous, forget them. They will only flaw the mirror cosmetically. By the way, Willmann-Bell sells a lot of useful grinding supplies.

Holding the mirror: Don't let your fingers touch the bevel of your glass while rotating the mirror during grinding and polishing. When you rotate the mirror, grab it closer to the center of the edge. Touching the bevel heats the glass, causing it to expand. Then you grind or polish the raised edge off, resulting in a turned edge when the mirror cools down.

Turned edge problems: These can be a problem with any type or thickness of glass. It's by no means restricted to thin mirrors — and it's just as often a problem with full-thickness pyrex mirrors. Most amateur mirrors in the 16"-plus size range suffer from this problem — but it often goes unnoticed despite its obvious effect on the images in the telescope.

Ordering sheet glass: Sometimes a rough round blank turns out to be longer across one diameter than the others by more than 0.25". Usually they scribe a circle on the glass, then cut up to it. If they do a sloppy job, the blank could be out of round. I'm not sure to what degree it effects the mirror, but it seems likely to cause astigmatism. (The problem is similar to figuring an elliptical diagonal without blocking it with glass keepers on the sides.) Be sure to specify that you want a blank as round as they can make it, within reason.

Fine grinding: I change from my rough grinding area to my fine grinding and polishing area after 220, not before. #220 is still gritty stuff.

The "W" stroke: This is a casual way of describing any stroke that goes forward and backward while progressing left to right or right to left on the mirror. Take four of five back and forth strokes while moving the mirror from one side to the other. By "short stroke," I mean to hang over front and back left and right only 1 or 2 inches while the tool is on top. During fine grinding it is a good idea to vary the stroke length a small amount to avoid digging a zonal groove where the strokes start and stop.

Pitch

Polishing begins with pitch, a viscous tar-like substance that serves as a carrier for polishing agent, usually a metal oxide in optical work. The pitch is coated onto, or formed into a tool that fits the optical surface to be polished. The type, hardness, and behavior of the pitch are important in determining the action of polishing.

I won't go into methods of hardening and softening pitch because these are already well covered in many books for TMs. My own experience is that for a large lap, any hardness within reason will do the job. I started making mirrors with straight resin pitch with a very small amount of turpentine added. These laps were extremely hard. Lately I have used some very soft pitch laps. They work well too. Very hard pitch laps can be a nuisance because they tend to act up a lot and begin to cut sporadically. Soft laps cut evenly, but can lose their shape and need a lot of maintenance. Still, you're better off if your pitch is a little on the soft side.

The best pitch I know is Swiss black tar pitch, which comes in different grades. Adolf Miller pitch #73 is what I recommend. Oddly enough, it is less expensive than many of the pitches available to amateurs. It comes in 1 kilogram tubes, at $7.50 each, and can be purchased from Fusco Abrasive Systems, 17899 S. Suzana Rd., Compton, CA 90221, phone: (213) 637-3427. Fusco also sells MicroGrit®.

A kilogram and a half of pitch will make one 16" lap. I would order three kilos just in case I messed up a lap, and to have extra on hand for smaller figuring laps.

Polishing Agents

For efficient polishing, choose one of the many cerium-oxide-based polishing agents such as Vitrox C, which is good for polishing, or Rhodite 15, which I like for figuring. But don't go nuts trying to find these particular brand names. There are lots of good polishing agents available from many different suppliers sold under many different names. Most of them will be quite suitable to your needs.

However, stay away from "super-fast" polishing agents used for metal mirrors. These will cut much too fast for your needs on a glass telescope mirror. I don't think you'll have to worry about being sold any, since I don't know of any being sold outside of the optical industry.

Pitch Base

Your pitch lap requires a base, something to pour the pitch on. It can be flat, or it can have the radius of your mirror on it. The grinding tool is traditionally used by TMs. The base must be thick enough not to flex, and can be made of thick glass, aluminum — even plaster has been successful. What you choose is up to you. I have always used 16" or 18" x 1" thick portholes. They make excellent pitch laps. If you try plaster, I again recommend Kerr Plaster® (mentioned in part 1) for its rigidity.

The diameter of the pitch lap, like the diameter of the grinding tool, is up to you to some extent. The closer the diameter of pitch lap is to the diameter of the mirror, the more likely it is to produce a spherical figure. However, I don't recommend everyone make a full sized lap because it's not always practical. For starters, a full size base for the lap is not always available. There is also the problem of managing a big lap. Furthermore, the larger the lap, the more work is needed to push it back and forth on the mirror, and the harder it is just to lug around from one place to another.

Sub-diameter laps tend to overcorrect the figure of the mirror, tending to push a sphere toward a figure that is spherical in the center and parabolic at the edge. This is a manageable problem — even desirable at times. It may prove to be a new experience to TMs who are used to parabolizing from a spherical surface.

The smallest polishing lap (as opposed to figuring laps, which are much smaller) that I've seen used was on a 25" f/6 mirror. It was polished it with an 18.75" lap — 75% of full diameter. The figure came out as described: with the center spherical and edges parabolic. It was corrected this quite easily using various sizes of figuring laps.

For a 16" mirror I would recommend a 16" lap unless a 16" base is not available. In a pinch, I would go to the 25% sub-diameter lap without anticipating too much added difficulty.

For mirrors up to 20", I still recommend the full size lap. Above 20", where laps usually become unmanageable for one person working by hand, I would recommend using a sub-diameter lap. But don't let this stop you, especially if you have a strong build and think you can handle a 24" lap.

Making the Pitch Lap

Pouring a pitch lap for a big mirror can be quite a job if you've never done it before. If you are not careful, as well as a little lucky, you may end up doing it all over again. Pouring a big lap requires timing, and until you have done it, it's hard to get everything to fall into place. Once you have done it, successfully or not, you'll have some feel for it, and it'll become much easier.

Start by heating the pitch on a hot plate. A 5 pound coffee can is an excellent container to heat the pitch in, and it will hold enough pitch to make a 20" lap. Heat pitch slowly. One or two hours is not too long. If you try to heat it in 15, or even 30 minutes, it will probably overheat at the bottom of the can.

While it is heating, stir it now and again. Use the time to clean the pitch base so the pitch will stick firmly to its surface. Make a dam at least ½" high around the base with masking tape. Be sure that the tape is strong enough to separate from your base when you strip it. This usually is no problem, but if the tape tears when you strip it, it does create a problem.

Prepare the area, too. Place the base on something solid and level for pouring the pitch. Be sure to have a water slurry of polishing agent handy and a little Ivory dish soap or Windex ready. A propane torch and matches are useful but optional.

When the pitch melts, pour a little on something and let it cool to make sure it is as hard or soft as you want it. Before you pour, be sure the pitch is hot enough to insure it will stick to the base. Smear water and polisher with 2 or 3 drops of soap or a small squirt of Windex on the surface of the mirror. Then light the propane torch and set it safely aside. Start by pouring a layer of pitch on the base to a maximum depth of ¼". Even if the base is convex, the pitch will flow into a more or less uniform layer.

At this point you should have about a quarter of the pitch still left the can. Don't set the pitch back on the hot plate: let it cool a little for the next step. Just how cool to let it get is one of the tricky parts of this job. You don't want it so cool that you can't get enough out of the can, and you don't want it too runny or it will fail to serve its purpose. When I do the first pour, if the pitch is hotter than I planned, I set it on the cement floor. If the temperature was right, I set it on a wooden counter.

Right after your first pour, flash the flame of the torch over the surface of the pitch. This will pop all the bubbles on the surface and leave it smooth. Check the mirror to be sure it is still wet with soap and polishing agent.

When the pitch lap has cooled to just the right temperature (this you must learn by experience), pull the tape off the base. The pitch should just run over the edge a small amount. If it does not run at all, you are behind schedule. If the pitch starts running quickly off the base, you pulled the tape too soon. You can monitor the pitch before you pull the tape by just starting to pull the tape and see how fast the pitch wants to run out of the crack.

As soon as you pull the tape, slowly pour more of the somewhat-cooled pitch right in the middle of the lap. If everything is at the right temperature, the new pitch will form a convex crown on the lap that will flow toward the edge. If there is time, flash this with the torch. By the time the crown reaches the edge zones of the lap, it should have cooled enough so it won't stick to the mirror. Grab the mirror, which should still be wet on the face with polisher and soap, wet its back so you can see through it, and lower it onto the pitch.

Start lowering the mirror tilted slightly so that it contacts one edge of the lap first. Then as you set it on the lap, tilt it level with the pitch. It is very important not to lower it level on the lap because you may trap a large air bubble in the center. Move the mirror around on the pitch and keep moving it as the pitch cools. If you stop, it will stick. Keep working until the lap is in contact with the mirror all the way to the edges. If you have a full-size pitch base, the pitch will ooze out somewhat bigger than the

mirror and the mirror may sink into the pitch. Push the pitch down and try to get the mirror moving around.

If you end up with a large space in the center, let the pitch cool, then separate the mirror, heat more pitch, and pour another crown. This is a common procedure for big lap and fast mirrors.

Finally, when the pitch is hard in the middle, you may stop and lift the mirror off. If you lift it off too soon, you will deform the lap when you separate them. Be sure the lap touches the mirror right to the edge. This whole procedure is done quite rapidly, although the timing depends on the temper and temperature of the pitch. If your lap base is glass, let it cool on its own after you separate them. Cold water may break it.

If your mirror is too heavy for you to pick up and turn over, place the pitch lap face down on the mirror instead of pressing the mirror on the lap. Again, let them touch at an angle to avoid trapping an air bubble which would deform the surface of the lap.

It is a good idea to keep a bucket of water nearby in case you get hot pitch on your hand. You can immerse your hand in it, then quickly get right back to work.

If the whole thing fails, you may be able to save it by heating up more pitch and pouring a layer right on top of what you have, then pressing the mirror on it. It is a good idea to heat the lap until it's tacky with the torch before pouring on new pitch.

Grooving

To allow the pitch to flow and conform to the mirror surface during polishing, the surface of the lap must be cut into facets. One method for doing this is to incise the face of the solid lap with grooves. For pitch laps under 20", I use a groove spacing of 1.5", so I will suggest the same thing for you.

Start by marking the center of the lap by a small "X" cut with a single-sided razor blade. Arrange the squares off center with respect to the X. Take a straightedge and mark, with razor blade lines 1.5" apart, where the grooves will go. Gently cut the grooves into the pitch, using single-sided blades, while running cold water on the lap. Cut down on one side of a line, then rotate the lap 180° and cut down the other side until the grooves are about ¼" wide. This job is very messy and is best done outside, or in a large sink, or on lots of newspapers. Pitch sticks to everything, and it is very hard to get out of clothing. You have been warned.

Pressing the Lap

Once the lap is grooved, you have to be sure it is "pressed" to conform precisely to the curve of the mirror. If you have a hard lap, warm it slowly in water or in the sun. Wet the mirror with polisher, then press them together. Put 40 or 50 pounds on top and leave them for a while. Keep them wet; if they dry up, they will stick together. If you have a softer lap, you can press it without heating it beforehand.

When the mirror will not be polished for a considerable time, for example, after the day's polishing, keep the lap face down on the mirror with a single piece of waterproof paper covering the entire lap. Butcher paper works well for this if it is the type that is coated with plastic instead of wax. Be sure the lap is dry or it will wrinkle the paper.

Don't let the lap sit on the mirror for more than a day or two or the squares will start to press out. For periods of pressing between polishing spells in a single day, just remember to keep the mirror moist.

Polishing

Polishing is the stage of mirror making that requires the most physical work, even more than rough grinding. What probably concerns you most is how much time it will take you to polish the mirror. Using the techniques described below, a 16" porthole takes about 10 hours to polish out with a full size lap. A pyrex 25" finished in 3 micron abrasive takes about 12 hours on a lap 18.75" diameter.

For those unfamiliar with efficient polishing techniques, these times may seem much too short. If you've ever put in 60 hours to polish out a 12" mirror, you'll suspect these mirrors must not be polished out properly, or their figure must be grossly defective due to the fast action of the lap. Neither of these is the case. I realize that many amateur mirrors never get perfectly polished out. My own first couple of mirrors suffered from this. I know how quickly a mirror can take a superficial polish that will look hazy when aluminized, but I'm talking about a real polish. These efficient polishing techniques produce an extremely even cut. Even though the friction is high, the work is done at a slow pace and produces a smooth surface texture.

Nor do I want to make these polishing procedures seem too easy. When I say 10 hours on a 16", that's not two afternoons — that's 10 hours actual time spent polishing. It is so physically demanding that I am only able to polish in 15 minute spells 2 or 3 times in an entire day.

You can not expect such short polishing times using a machine. Normal machine polishing techniques are not as efficient as hand polishing in these sizes. But don't get me wrong about machine polishing: it is the only way to go. I work with them all day in my profession and precision optical production would be impossible without them. Just don't feel that you're at a disadvantage for making a mirror with your own hands.

To start with, mix your polishing agent with water. The amounts of each to be used can vary quite a bit depending on how you like it, or on the brand of polisher you use. Start with 2 or 3 tablespoons to a cup of water. If you realize it's too thick, add a little water later. After mixing, strain the mix through cheesecloth to remove lumps.

Use a squirt bottle to apply polisher and water. Squirt bottles come in many shapes and sizes. You can find suitable bottles in sporting goods stores — they are used by distance runners and other athletes — or make your own by putting a small hole in the top of a plastic bottle and turning the bottle over to squirt the polisher on the mirror. An additional squirt bottle filled with water is also helpful.

"Wet press" the pitch lap before starting. Squirt polishing compound on the mirror, then set the lap on the center of the mirror. Load about 40 pounds of weights on the lap and let it sit for 15 minutes. Be sure that it does not dry up. Take off the weights. Now you're ready to start.

Begin polishing by moving the lap around to stir up the polish on the mirror. Add a little water if it needs it. Move the pitch lap slowly back and forth in your polishing stroke. I recommend the "W" stroke. Starting with a left overhang, push the lap forward over the front of the glass, then pull it back. Work slowly — each stroke should take one to two seconds. After four or five strokes, you'll be over on the right. Continue the forward and back motion while progressing to the left side. At the same time, walk slowly around the barrel. Rotate the lap every now and then, or continuously, as you prefer.

The length of the stroke, and hence the amount of overhang, can vary from just a couple of inches to 5 or 6

depending on your circumstances. With a sub-diameter lap, avoid making the stroke too long or you may end up overcorrecting the mirror. With a full-size lap there is little danger of this, and you can use longer strokes.

Judging the "Feel" of the Lap

How well the polishing lap works depends on several things. You can judge its performance by the "feel" of the lap. Most of all, you want the lap to be extremely hard to push. It should move only with a great deal of effort on your part, and then it should move slowly and smoothly across the mirror. This should cause blisters on your hands after a while. I recommend leather gloves, or tape on your hands in tender areas, or both. You may have trouble finding gloves that don't slip on the back of the lap. I've found that snug gardening gloves work well when they're a little wet.

It is during "tight" and "smooth" polishing that the mirror polishes quickly. The lap and the mirror are in full contact, you are pushing hard, the polishing action is generating heat, and the glass is polishing rapidly but evenly. Often amateur optical workers seem to be afraid when the lap begins to function correctly. They can tell that something is happening. So they stop and add more water, or more polisher — anything to make the lap slide easily again. This is the wrong thing to do: when it's right, keep working.

Often the lap just slides around on the mirror with little or no drag at all. This loose and skiddy action is all wrong. Or it may slip and stick suddenly again, feeling anything but smooth. These problems often happen when the pitch is too hard, or too cold (due to your climate), or just cold from the night before. It may also be that the lap is not grooved well enough or has not been pressed in contact. Quite often laps will do this for no discernible reason.

The remedy that works almost 100% of the time is heating the lap. You can warm it by submerging it in hot water (about 43°C) for 5 minutes. Sunshine or a sunlamp also work well. Be careful not to heat it too much if you have soft pitch. You may have to heat the lap only once to cure it, and it may work well from that day on. You may have to heat up the lap every day you polish. Learn to love your pitch lap and cater to its idiosyncracies.

Another possible remedy is walking around the barrel in the opposite direction. For some reason, pitch laps seem to have a direction (either clockwise or counterclockwise) that they like to go. They also seem to change their preferred direction at any time. Experiment with the phenomenon as polishing progresses.

How much pressure? Lots: a slipping lap may result from lack of pressure on your part. Lean on it!

The opposite can happen also. The lap may be working so well that one person can't push it. Usually reversing the direction you are rotating things will help. Walk around the barrel the other way, turn the mirror the other way, turn the lap the other way, etc. Making the polisher slurry either thicker or thinner may work. As a last resort you can lubricate it with 2 or 3 drops of Ivory dish soap in your squirt bottle. In any case, you want to get the lap working right or your mirror will take many more hours to polish.

Holding the Lap

Once you get things working right, you will have to experiment with different ways of holding the lap to push it back and forth. I always grab the lap over the far edge at 10 o'clock and 2 o'clock and rest my forearms across its back. This allows me to put my weight on the lap and also gives me a smooth transition between forward and backward strokes. Another method is to put one hand on the far side of the lap at 12 o'clock, with that forearm resting on the back of the glass, and the plam of the other hand on the near side of the lap at 6 o'clock. It does not seem to harm anything if you have to hesitate between reversing the forward and backward stroke.

Don't push the lap rapidly back and forth. It should take 1 or 2 seconds to complete one stroke. This may sound fast, but it is actually quite methodic.

Squirt polish or water on the mirror when it starts running dry. Be sure to rotate the mirror every time you complete on revolution around the mirror. Rotate it in the opposite direction from the direction you are walking. Vary the amount of rotation a little each time, and vary the point at which you stop to rotate the mirror.

Don't try to do more than 15 minutes at one time or you may end up hurting yourself. I recommend you do about 15 minutes, then rest for 30 minutes, then do another 15 minutes, then quit for the day. After you get used to it, you can determine your own pace.

Don't let all this deter you. Once you master it, you will think nothing of setting up a routine of polishing 2 or 3 times a day for 15 minutes and you'll get a 16" mirror polished out in 2 weeks. You can't expect to polish out your first big mirror in the minimum amount of time. Go easy, especially while you're still somewhat tender in the muscles and tendons of the shoulders and arms. There is nothing wrong with taking twice as long on your first mirror as you would on your second.

Completing the Polish

It is not difficult to misjudge the polish on a mirror. Your first goal is to completely polish out the mirror in this stage before going on to figure it. If you make the assumption that the mirror will get polished out while figuring, more often than not, you'll end up with a figured mirror that is not polished out.

When checking the polish, there is one thing you can count on: if it looks underpolished at all, it is probably worse than you think it is. The 25" f/6 mirror which I mentioned earlier looked very nearly polished after 7 hours of work. It took another 5 hours to polish it out completely.

The first and most widely known method of checking polish is to focus light on the surface. In the initial stages of polishing, use a pen-light that focuses a bright beam of light. Shine it on the cleaned surface of your mirror — right away you'll see the beam on the surface. As polishing progresses, you can monitor which parts of the mirror are polishing quickly and which parts are lagging behind. Keep records, and continue to check the parts that originally lagged behind so they get fully polished.

When this gets ineffective, put black paper under the mirror to give a dark background. Focus an image of the filament of a bright desk lamp on the surface of the mirror with a positive lens such as a magnifying glass. Angle the light at approximately 45° so that the back of the mirror is not illuminated under the area being observed. If there is still haze on the mirror, you will be able to see the image of the filament on the surface.

When no haze is left, it will be virtually impossible to see the surface. You may find it difficult to get the surface clean enough so you are not just looking at dust or oil or leftover polishing agent. If it passes naked-eye inspection, examine the focused beam on the surface with a magnifier such as a low power eyepiece. Experiment with different angles from which you observe the surface, and do not consider polishing completed until it is completed.

Test Stand & Testing Tunnel

If you plan to do all the testing of your mirror in the telescope itself (an option which I will discuss in part 3 of this series), you won't need a test stand and testing tunnel. However, you will be better off to learn how to evaluate the mirror's condition at the center of curvature, indoors under controlled conditions, even if final figuring is to be done in the telescope outside. If you plan on testing the mirror indoors, your testing environment is extremely important.

The test stand must allow the mirror to hang freely in a sling while resting on a piece of shag carpet. The sling can be made of any flexible material that bends to the circumference of the mirror. Nylon or plastic straps are most common; I prefer old seat belts myself. The strap must not support over 180° of the mirror or the strap will squeeze the mirror. Nor should it support much less than 160° or the strap will oversupport the bottom of the mirror.

The sling should be hung in such a way that the surface of the mirror rests about ¼" forward of it. If the mirror is thicker than the strap is wide, then center it around the middle of the edge. The carpet just sits behind the mirror. I use the same piece I polish on. In the vertical position, the mirror rests lightly against the carpet, and so serves as a satisfactory support.

If you plan to do the critical testing "in the lab," you must take steps to shield the optical path from air currents. Your test area must be twice the focal length of your mirror and allow space for your test stand, the tester and you. If you are fortunate enough to have a room long enough to accommodate the test, you may be able to cover up the cracks under the doors and close windows and air vents. However, if the test path must traverse more than a single area in the house, you will need to close all the doors and windows in the test area and possibly in the entire house. Close off any large airways that lead to other parts of the house, especially near the mirror. Large sheets of plastic work well; paint stores carry large plastic drop cloths, and I have seen rolls of plastic 10 and 12 feet wide sold in hardware stores.

Testing

If you are unfamiliar with mirror testing, you should learn about it. Testing is discussed in several TM books, including ATM Book 1. At this stage, you will begin to realize how crucial previous optical experience with smaller mirrors of conventionasl thickness is for making a large thin mirror. For this article, we assume you have some test experience or have the help of someone who has, and that you understand the basics of testing in this manner.

When the mirror looks shiny enough to test, test it, since you must verify early that it is good enough to continue working on. Although 15 minutes of polishing will permit some testing, a shine suitable for evaluating the mirror will probably require an hour.

Begin by setting up to test the mirror with a 100 or 150 line Ronchi screen. This is an excellent quick test for overall quality and smoothness of figure. Excellent Ronchi screens can be purchased from Edmund Scientific Company. When you first look at your mirror with a light source at center of curvature, it may not look evenly illuminated. It is difficult to describe what degree of unevenness in the illumination at this stage is serious. If you have a dark area, usually the center or edge, examine it closely to see if it is properly ground out. If you can see many large pits, return to fine grinding and remove them.

If the area is free of pits, test the mirror with the Ronchi screen to see if there is a gross zone within the unpolished area. If there is, you may need to regrind the mirror, or you may be able to polish it out. Dark spots are caused by your tool bending in to the middle while grinding or by using too long of a stroke. The shape of the mirror then deviates so greatly from a sphere that the polishing lap cannot reach all of it.

If the area looks reasonably good, just keep track of it during polishing to see if the problem remedies itself within 4 or 5 hours of polishing. If you have been proceeding according to this article's instructions, very few of you should have to deal with this. Normally the mirror will look more or less evenly illuminated after an hour of polishing.

Next, estimate how much the mirror departs from a sphere. If you have been using a full-sized lap, it is very likely you have almost a spherical surface. A sub-diameter lap will probably have a progressively longer focus toward the edge. If you are working plate glass and you test right after polishing, it will look overcorrected and in 3 hours or so, if the lap was warm, it will settle down and look more nearly spherical.

If the figure looks reasonably spherical, you're on Easy Street! Just test for astigmatism and then continue polishing. If the curve is an overcorrected sphere, i.e., a parabola or hyperbola, check the uniformity of the curved Ronchi bands. Even though the Ronchi lines bow, they should bow with no gross breaks or zig-zag areas indicating a gross zone. If this is the case, and several hours of continued polishing produce no appreciable improvement, you must investigate your fine grinding techniques and try again from #400 or 12 micron abrasive.

Next, you'll want to determine approximately how overcorrected the mirror is. The difference between the focus at the edge and at the center of a parabola tested at the center of curvature with a stationary source and moving knife edge is:

$$r^2/R$$

where r is the radius of the mirrors (i.e., half of the diameter), and R is the Radius of curvature, or twice the focal length. For a 16" f/5 mirror, it is:

$$8^2/160 = 64/160 = .400$$

If your mirror exceeds this by more than 10% or 20%, take some steps to reduce it early in the polishing process. Crude measurement of the correction is a simple matter especially if you are experienced with a Foucault tester; just measure the difference of the focus of the edge and of the center. If your light source moves with your knife edge, divide the focus difference by 2. For a 16" f/5, it would be 0.200.

You can also check for overcorrection with a Ronchi tester by placing the nulled zone on the edge of the mirror, marking where the screen is, then nulling the center and marking the position. Even measuring the difference between the lines with a ruler will tell you if things are all right. Once again, remember to divide by 2 if the light source (whether it's a pinhole or the other side of the screen) moves with the testing Ronchi screen. If the correction is too great, shorten your polishing stroke for a while.

Usually long "W" type strokes made with a sub diameter lap or larger will tend to overcorrect a sphere toward a parabola, while short "W" type strokes with a 1" overhang will bring the mirror much more spherical. In the case of a full-size lap, short strokes can even undercorrect a sphere. With a sub-diameter lap, you might make the center portion a slightly undercorrected

sphere while the edge becomes overcorrected. A very short stroke will make the edge more difficult to polish out. You will find out, with time and experience, which stroke length or lengths are right for you.

Testing for Astigmatism

At this stage your mirror should have no astigmatism. If it does, something is wrong. In testing for astigmatism, you will find out why it took so long for thin mirrors to become popular — and if things go well for you, you will learn why they eventually became accepted.

The trouble with testing thin mirrors for astigmatism is that when they are being tested vertical, they quite often bend. Even a good mirror may look astigmatic. This is another reason why thin mirrors are not used much in the optical industry, since most optical elements are used vertical. The problem becomes manageable in telescopes, where the mirror most often faces above the horizon in its floatation cell.

Astigmatism, or cylinder as it is often called, happens when one axis of the mirror has a shorter focus than the other. This shows up in the telescope as star images that don't quite focus. As you rack through focus, star images on either side of focus are elliptical in shape, with axes at right angles.

To test indoors for astigmatism at the center of curvature, examine a small illuminated pinhole with an eyepiece of approximately 9mm focal length. Make pinholes by poking the smallest hole you can in a piece of tin foil or .001 thick brass shim stock. A small sewing needle works well. You will discover all kinds of ways to make smaller and more uniform pinholes by putting the brass on different things and poking it different ways with the needle. If you get too good at it, you may have trouble getting enough light through your pinhole.

Place the pinhole in front of a light, preferably the bulb of your Foucault/Ronchi tester, and look at the image of the pinhole at the center of curvature with an eyepiece. Make the distance between the pinhole and the eyepiece as small as you can or off-axis aberrations will confuse you. Keep stray light from entering the eyepiece or the image of the pinhole will be washed out, and make sure the eyepiece is as square as you can make it to the optical axis of the mirror.

A non-astigmatic image is perfectly round on either side of focus and through focus. Don't unfocus the image too far, because you are interested in examining the pinhole very near focus. Depending on the figure of the mirror, the inside focus may be too soft for this test. Outside of focus you'll see a sharp bright ring on the edge of the image due to the edge focusing long. This should be round.

Don't mistake irregularities in the roundness of the pinhole for problems in the mirror. The image will take on the shape of the pinhole when the image focuses. Be aware that air currents can disturb this test.

If you don't see a round image, make sure your eyepiece is square on, then rotate the eyepiece to make doubly sure it is not the fault of the eyepiece. Tilt your head to make sure it is not your eyes.

Make a note as to the shape and orientation of the problem and which side of focus you're on. Then take the mirror off the sling, and without rotating it, reposition it on the sling again making sure it hangs freely and evenly against the carpet. Inspect the image again. If the problem now looks significantly different, then your mirror is not well supported on the test stand.

If the image still looks the same, rotate the mirror 45° in the sling and again observe the out of focus image. If you still see astigmatism but it has not rotated with the mirror, then it is due to bending in the vertical position. If this is the case, you can probably make the astigmatism come and go depending on just how the mirror rests in the sling. Develop a technique for putting the mirror in its sling to minimize the effect — and then ignore it. Since it will probably be in the horizontal and vertical directions, it will not significantly affect your testing of the mirror.

With thin mirrors, this bending problem sometimes takes a form not quite like astigmatism. Sometimes called "potato chipping," it means the bottom of the mirror is bent, but the top is not. You may see round images with a flat spot on the bottom outside focus image, the bottom area having more light in it.

Even if you see a round image apparently free of astigmatism, rotate the mirror anyway to make sure that astigmatism in the mirror has not cancelled astigmatism due to the support system.

The bad news starts if the problem rotates reliably with the mirror. If the astigmatism is very slight or difficult to detect, there is a chance it will polish out. I do not recommend trying. Polishing out astigmatism by hand may prove fruitless and you can waste a lot of time and a great deal of energy.

Make one final check before despairing. Allow the mirror to come to thermal equilibrium, at least 3 to 4 hours, and then retest it. Some portholes become astigmatic while cooling.

If it is astigmatic, the solution is to go back to #400 or 12 micron grit, whichever you used, and grind again. Be extremely scrupulous in applying all the precautions outlined in part 1. Make sure the back is flat. If you are using a porthole and you did not grind the back flat, do so. Did you forget and let the carpet pile get smashed down? If the tool was on the thin side, maybe it was too thin. Examine your rotating techniques to insure you are rotating by random amounts, and not repeating positions.

Carefully determine and mark the axis of the astigmatism on the mirror. If it returns after grinding, you can see if it lies in the same axis of the mirror as it did the first time or not. If it does, it could indicate bad glass, or that the back is not flat. Even if the tool is too thin, the astigmatism should be less the second time.

Of course, the mirror can be tested for astigmatism in the telescope — just apply the same tests using a star. The diagonal adds another variable because it will introduce astigmatism if it is not flat. Nine and eight point flotation systems can also do strange things if not properly constructed or used.

The main disadvantage of astigmatism testing in the telescope is turbulence. Air turbulence blurs the image, hiding the problem if it is small. Also, uneven temperatures in the air in the tube can cause oblong star images. However, when the air is still, there is no more practical test for astigmatism than observing a star through a high-power eyepiece.

The Next Step

At this point — with the mirror polished out and free of astigmatism — you are ready to tackle figuring. Most of the physical labor is behind you and the work of the mind is before you. Even the most experienced opticians can find figuring a study in frustration. But the feeling of accomplishment when you complete something as rewarding as a large telescope mirror will make all the labor and frustration worthwhile.

Bob Kestner
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Lens Design Fundamentals

by Rudolf Kingslake

Since 1929, those wishing to learn the art of designing lenses and optical systems have relied on A. E. Conrady's *Applied Optics and Optical Design*. It was the first book in English to give detailed information on how to correct the aberrations found in optical systems. The publication was to professional lens design what Albert G. Ingalls's *Amateur Telescope Making* book was to the art of telescope making.

If such a standard work is still sufficient for learning and training purposes, why has Rudolf Kingslake, an associate of the late Dr. Conrady and also his son-in-law, published a new book? Mainly because of the changing times; in the past 50 years, logarithmic tables and hand calculations were replaced first by the mechanical desk calculator and now by the electronic calculator or computer. The formulae used for logarithmic ray tracing work are not suitable for calculators or computers, and the speed and capacity of the electronic machines has freed the lens designer to employ methods of evaluation that were impractical earlier. In his preface, Dr. Kingslake states, "This book can be regarded as an extension and moderization of Conrady's 50-year-old treatise." The result of the modernization is that the presentation and formulae are suited to for scientific calculators and minicomputers by math-minded amateur telescope makers.

Lens Design Fundamentals is a good book for the beginning optical designer. It is carefully structured to lead the reader through the aberrations of lenses and at the same time it gives basic insight into the causes and effects of the aberrations. Where possible, a basic lens such as a two-element achromat is evaluated for errors and then, if it is necessary, Kingslake shows how to redesign the lens to eliminate or keep them within tolerance.

The material in the book is assembled from lecture notes given in Dr. Kingslake's classes at the University of Rochester Institute of Optics for more than 30 years. It is a common practice for professors to use class notes and research for a textbook, but some readers might question the modernity of material so venerable. Consider, however, that there are no optical texts that do not in some way, directly or indirectly, use basic material from Conrady. The cutting edge of optics may change and advance, but the basics still remain the basics! If asked, hundreds of former students now busily engaged in optics would confirm the value of the notes they gathered in Kingslake's classes.

The contents page lists sixteen chapters that cover the following subjects:

Chapter 1, The Work of the Lens Designer; Chapter 2, Meridional Ray Tracing; Chapter 3, Paraxial Rays and First-Order Optics; Chapter 4, Chromatic Aberrations; Chapter 5, Spherical Aberration; Chapter 6, Design of a Spherically Corrected Achromat; Chapter 7, Oblique Pencils; Chapter 8, Coma and the Sine Condition; Chapter 9, Design of Aplanatic Objectives; Chapter 10, The Oblique Aberrations; Chapter 11, Lenses in which Stop Position is a Degree of Freedom; Chapter 12, Symmetrical Double Anastigmats with Fixed Stop; Chapter 13, Unsymmetrical Photographic Objectives; Chapter 14, Mirror and Catadioptric Systems; Chapter 15, Eyepiece Design; Chapter 16, Automatic Lens Improvement Programs.

Obviously, if the emphasis of the book is on lenses, and only one part, Chapter 14, is devoted to mirrors and catadioptric systems, why should this publication be of interest to telescope makers who use mirrors in most instruments? Except for color aberrtions — chromatic errors — a mirror or system of mirrors can have all the other errors found in lenses in the formation of the images. Therefore, the study of aberrations in all optical systems is of prime importance. The change in the formulae used is quite simple: for the index of refraction of the glass substitute -1, then apply the equations in the regular manner.

It is also important that many modern astronomical instruments use both lenses and mirrors to achieve their final correction. Among them are Schmidt-Cassegrain and Maksutov telescopes. All large professional reflecting telescopes built today depend on lenses close to the focus to flatten the field for photographic purposes and to extend the coverage of the mirror system. In the past few years, a number of all-spherical telescope systems of lenses and mirrors have been published for the telescope maker. The Jones/Bird design is an excellent example of the marriage of lenses and mirrors to produce a fine instrument. An interesting project for the fledgling designer, once the art is mastered, would be to design an astrographic lens for astrophotography.

How to start designing lenses by trigonometric methods is found in chapters 2 and 3, and the formulae described in them are used throughout the rest of the book for the evaluation of optics. The meridional raytrace, or exact raytrace (as it is sometimes known), is the determination of the aberrations of lenses and systems and should be fully understood before going any further in optical designing.

However, the baseline for determining the magnitude of errors is the paraxial raytrace covered in chapter 3. In many investigations of a simple lens, such as a meniscus close-up lens for a camera, paraxial evaluation of curvatures and thickness is sufficient. As raytracing by trigonometry is time consuming even with a calculator, as Dr. Kingslake mentions, considerable time can be saved by a graphical raytrace and first-order layout of a system before a trigonometric begins. This is described in chapters 2 and 3.

There are many approachs to ray tracing. Some use shortcuts to find the answer, while others cover all aspects of how the ray of light travels in optic. Consequently, Kingslake introduces several methods with the advantages and disadvantages discussed. It is a good idea for a beginner to concentrate on the most informative in his first study of the book. In optics, it is best to know your subject thoroughly before seeking short cuts.

A number of ray tracing programs for simple calculators have been published.

Most of them use the formulae and approach outlined by Dr. Conrady in his books, but adapted to a modern calculator. As Kingslake points out on page 24, "...this method is seldom used today because L (distance to the object) can become infinite, and in any case the method breaks down for a long radius or a plane surface. Neither of these possibilities is acceptable when writing a computer program for tracing rays, and consequently today other methods are invariably employed." Conrady's methods are workable but they are awkward and inconvenient by today's standards. Kingslake has brought learning ray tracing up to date.

In the various chapters, the discussions of aberrations and their corrections are really much longer than implied by the number of pages. Often, it is assumed that the reader has himself done a paraxial and meridional raytrace of the lens, often in several wavelengths of light, so generally only the final result is discussed.

There is a lot of work in raytracing a lens or system, but it is rewarding and interesting to those who try it. It can't be emphasized strongly enough that a lens designer must be systematic. Even if it seems unnecessary at first, use the tabular system for calculation as shown in the book. If you are serious in the study of lens design, it might pay to have forms printed at some place like Qwik-Print.

There are a few errors in the book, but two in particular should be brought to the reader's attention. In discussing aplanatic surfaces on page 105, the author notes "...that such a surface is capable only of increasing the convergence of converging light or increasing the divergence of divergent light." However, the illustration on the same page shows this is not the case. It would seem that this error is really an omission, as in Kingslake's class notes this problem does not appear.

In a similar manner, Kingslake states on page 305, "A convex hyperbolic mirror is used in the Cassegrainian telescope, and a concave hyperbola is used in the Ritchey-Chretien arrangement." The material implies a concave secondary mirror in the telescope, which is incorrect. A Ritchey-Chretien has a convex hyperbolic secondary as well as concave hyperbolic primary.

A statement on page 298 about baffles in astronomical telescopes not being needed is false. Baffling a Cassegrain type telescope is vital to its performance if the focus lies just behind the primary mirror. Only for the coude focus deep in the observatory, reached by several reflections off flat mirrors, is the need for baffles not urgent. This could be further clarified.

The finding of the sagitta of a mirror or lens is important for its fabrication. In the book you will find that it is not to be located on page 27 as indexed, but on page 29. The formula on page 29 for finding the sagitta when very long radii are given can be valuable and is worth noting.

If one is not an optical engineer or college graduate, but has an average mathematical high school background and wishes to investigate lens design, then Kingslake's book will probably be an ideal text. No book is in itself complete and ideal. With time and experience, you'll expand into more elaborate fields of optics and design, but for beginners this book is highly recommended. It sits on my desk at work and has been a valuable reference since I first received it, and there is a second copy in my library at home where I also use it.

Robert E. Cox

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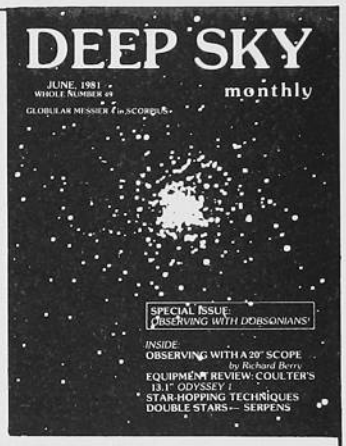

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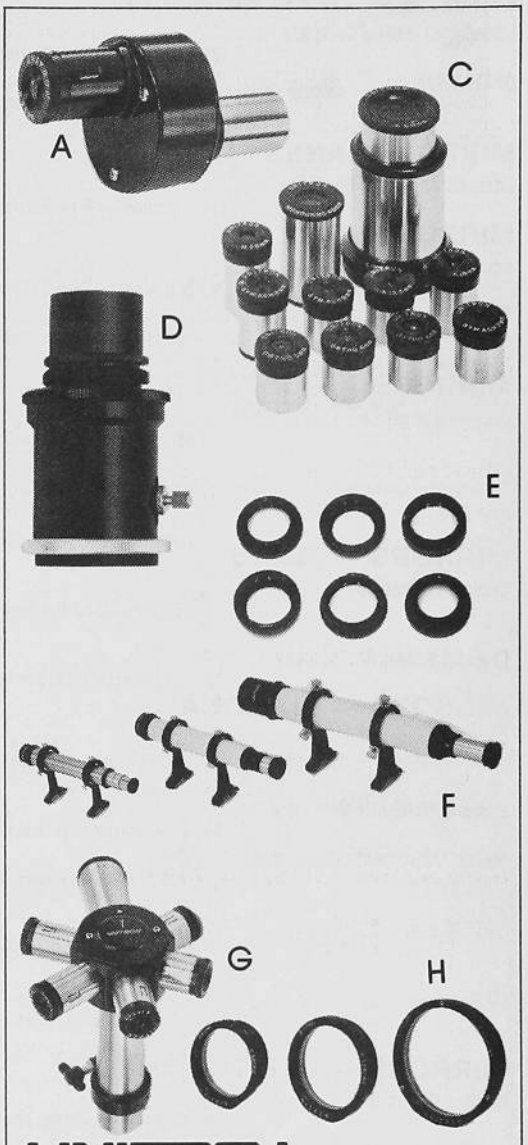

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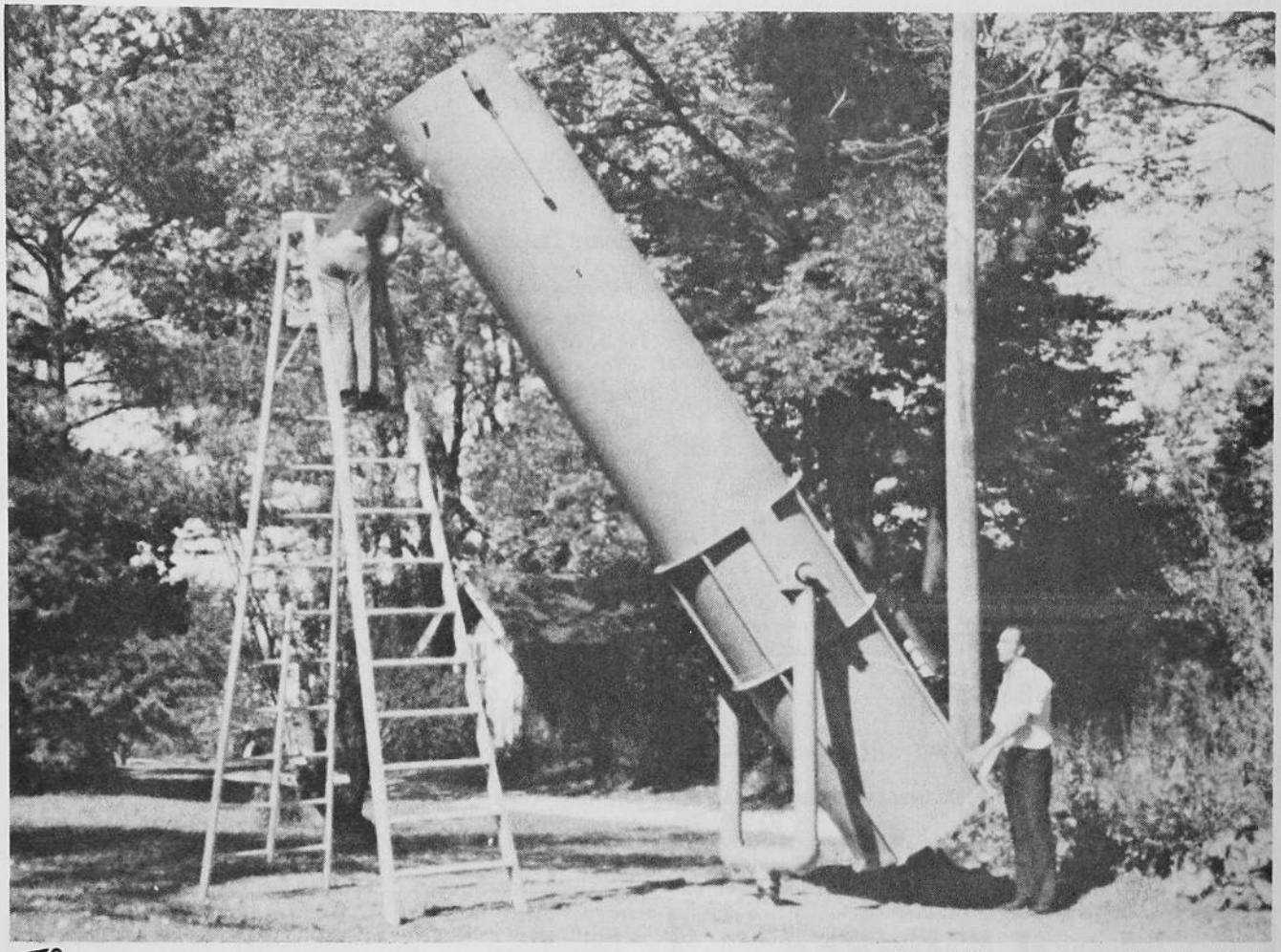

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Although it's now disassembled, the 31" f/7 Newtonian operated in northern Ohio by Norm Oberlie was once one of the largest amateur telescopes in the world.

skill, or the equipment, or the time to make a large telescope. So, if you think there are good reasons to buy a commercially made telescope, how can you protect yourself?

The first advice that I can offer is to be patient and not let "aperture fever" get the best of you. I wanted to believe that the telescope would be good in spite of all the clues that I saw. Every con man is successful because the sucker wants to believe.

Of course, there are always legal remedies. But they are expensive, time consuming, and depend on there being some assets to recover.

One thing that I will advise — never sell a good telescope in order to finance an unknown. I have wished many times that I have my 12.5" back. It was a good telescope.

Another recommendation that may be obvious to others, but wasn't to me, is never make full payment until you are sure that the mount works and the mirror forms a good image.

Meanwhile, unless there are some radical changes in the telescope business, everyone must try to protect themselves. The theme for the future will remain: CAVEAT EMPTOR!

Best wishes for fair weather and dark skies,

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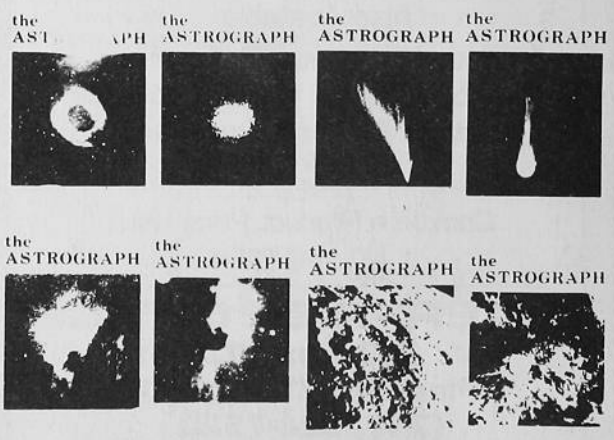
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